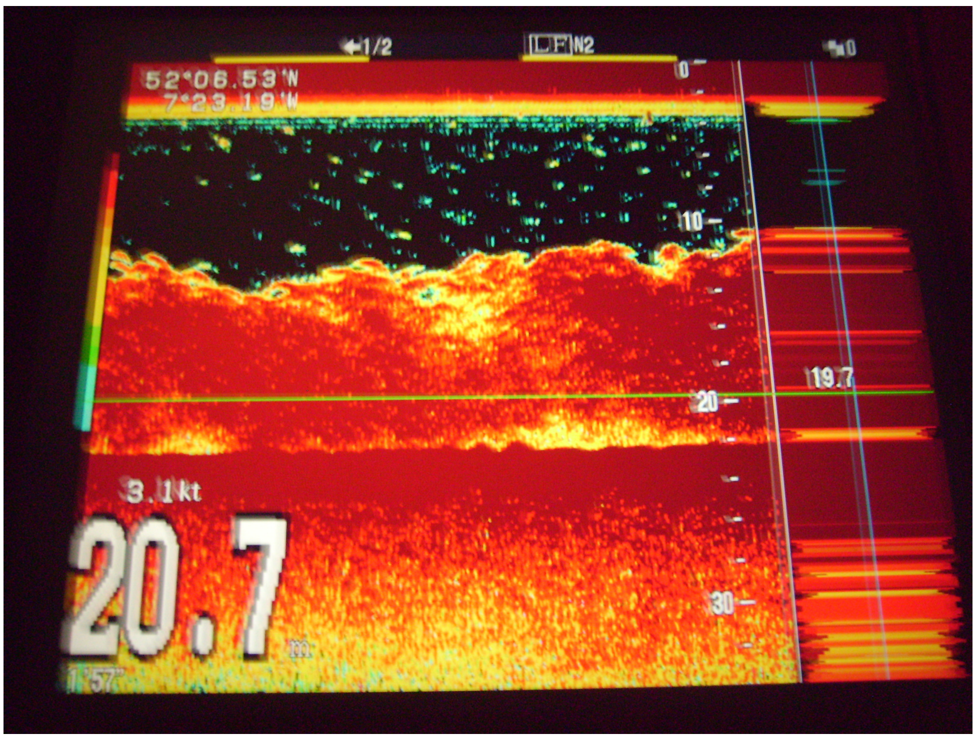
FSS Survey Series: 2010/03

Celtic Sea Herring Acoustic Survey Cruise Report 2010



Extensive school of herring around Helvick Head (ships 38 kHz navigation echo-sounder)

Ryan Saunders[1],Ciaran O'Donnell[1], Andrew Campbell[1], Deirdre Lynch[1], Afra Egan[1], Kieran Lyons[2] and Dave Wall[3]

[1]The Marine Institute, Fisheries Science Services,

Rinville, Oranmore, Co. Galway.

[2]The Marine Institute, Ocean Science Services

[3] Irish Whale and Dolphin Group (IWDG)

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1 Introduction

In the southwest of Ireland and the Celtic Sea (ICES Divisions VIIaS, g & j), herring are an important commercial species to the pelagic and polyvalent fleet. The local fleet is composed of dry hold polyvalent vessels and a small number of purpose built Refrigerated seawater vessels (RSW). The stock is composed of both autumn and winter spawning components and the fishery targets pre-spawning and spawning aggregations. The Irish commercial fishery has historically taken place within 1-20 nmi (nautical miles) of the coast and focused on aggregated schools within the spawning cycle. In recent years the larger RSW vessels have actively targeted offshore summer feeding aggregations in the south Celtic Sea. In VIIj, the fishery traditionally begins in mid September and is concentrated within several miles of the shore including many bays and inlets. The VIIaS fishery peaks towards the year end in December, but may be active from mid October depending on location. In VIIg, along the south coast herring are targeted from October to January at a number of known spawning sites and surrounding areas. Overall, the protracted spawning period of the two components extends from October through to January, with annual variation of up to 3 weeks. Spawning occurs in successive waves in a number of well known locations including large scale grounds and small discreet spawning beds.

The stock structure and discrimination of herring in this area has been investigated recently. Hatfield et al. (2007) has shown the Celtic Sea stock to be fairly discrete. However, it is known that fish in the eastern Celtic Sea recruit from nursery areas in the Irish Sea, returning to the Celtic Sea as young adults (Brophy et al. 2002; Molloy et al., 1993). The stock identity of VIIj herring is less clear, though there is evidence that they have linkages with VIIb and VIaS (ICES, 1994; Grainger, 1978). Molloy (1968) identified possible linkages between young fish in VIIj and those of the Celtic Sea herring. For the purpose of stock assessment and management divisions VIIaS, VIIg and VII j have been combined since 1982.

For a period in the 1970s and1980s, larval surveys were conducted for herring in this area. However, since 1989, acoustic surveys have been carried out, and currently are the only tuning indices available for this stock. In the Celtic Sea and VIIj, herring acoustic surveys have been carried out since 1989, and this survey is the 19th in the overall acoustic series or the sixth in the modified time series (i.e. conducted in October).

The geographical confines of the annual 21 day survey have been modified in recent years to include areas to the south of the main winter spawning grounds in an effort to identify the whereabouts of winter spawning fish before the annual inshore spawning migration. Spatial resolution of acoustic transects has been increased over the entire south coast survey area. The acoustic component of the survey has been further complimented by detailed hydrographic and marine mammal and seabird work programs first initiated during this survey in 2004.

2 Materials and Methods

2.1 Scientific Personnel

FSS	Ryan Saunders	Acoustics (SIC)
FSS	Afra Egan	Acoustics
FSS	Andrew Campbell	Acoustics
FSS	Ciaran O'Donnell	Acoustics
FSS	Helen McCormick	Biologist
FSS	Tobi Rapp	Biologist
FSS	Kieran Mc Cann	Biologist (Deck Sci)
FSS	Deirdre Lynch	Biologist
IWDG	Dave Wall	Marine Mammal Obs.
SWFB	John O' Regan	Fisheries Observer

2.2 Survey Plan

2.2.1 Survey objectives

The primary survey objectives are listed below:

- Carry out a pre-determined survey cruise track
- Determine an age stratified estimate of relative abundance of herring within the survey area (ICES Divisions VIIj, VIIg and VIIaS)
- Collect biological samples from directed trawling on insonified fish echotraces to determine age structure and maturity state of the herring stock
- Collect ancillary information on secondary pelagic species such as sprat and pilchard to determine biomass and abundance within the survey area
- Collect physical oceanography data as horizontal and vertical profiles from a deployed sensor array.
- Survey by visual observations marine mammals and seabird abundance and distribution during the survey

2.2.2 Area of operation

The autumn 2010 survey covered the area from Loop Head in ICES Division VIIb (Figure 1) in Co. Clare and extended south along the western seaboard covering the main bays and inlets in Divisions VIIj & VIIg. The survey started in the north and worked in a southerly direction to facilitate temporal progression of spawning within stock components.

The survey was broken into 2 main components (Table 1). The first, a broad scale survey, was carried out to contain the stock within the survey confines and was based on the distribution of herring from previous years surveys (O'Donnell *et al.,* 2004; 2005a; 2005b; 2006; 2007; 2008). The broad scale survey was composed of 10 strata and formed an integral component of the overall survey. Broad scale outer lying areas form an important transit area for herring migrating to and from inshore spawning areas and from offshore summer feeding grounds. The second component of the survey focused exclusively on known spawning areas and was made up of 6 strata.

2.2.3 Survey design

A parallel transect design was adopted with transects running perpendicular to the coastline and lines of bathymetry, where possible, within each strata. Offshore extension reached up to 65nmi (nautical miles). Transects resolution was set at between 2 - 4nmi for the broad scale survey and increased to 1nmi for the spawning ground surveys. Bay areas were surveyed using a zigzag transect approach to maximise geographical coverage within these confined areas.

Transect start points within each stratum are randomised each year using a random number generator within established baseline stratum bounds.

In total the combined survey accounted for 3,192 nm, with around 2,700 nm of integrateable acoustic transect data collected.

2.3 Equipment and system details and specifications

2.3.1 Acoustic array

Equipment settings for the acoustic equipment were determined before the start of the survey program and were based on established settings employed by FSS on previous surveys (O'Donnell *et al.,* 2004). The settings used on the *Celtic Explorer* acoustic array are shown in Table 2.

Acoustic data were collected using the Simrad ER60 scientific echosounder. The Simrad split-beam transducers are mounted within the vessel's drop keel and lowered to the working depth of 3.3m below the vessel's hull or 8.8m below the sea surface. Four operating frequencies were used during the survey (18, 38, 120 and 200 kHz) for trace recognition purposes, with the 38 kHz data usually used to generate the abundance estimate.

Whilst on survey track the vessel is normally propelled using DC twin electric motor propulsion system with power supplied from 1 main diesel engine, so in effect providing "silent cruising" as compared to normal operations (Anon, 2002). During fishing operations normal 2 engine operations were employed to provide sufficient power to tow the net.

2.3.2 Calibration of acoustic equipment

Due to time pressures at the start of the survey, calibration of the ER60 was postponed until the end of the survey. The calibration experiment was carried out in Dunmanus Bay (30 m water depth) on the 25th of October during hours of daylight. Good calibration results were obtained for the 18, 120 and 200 kHz transducers, but erroneous results were collected at 38 kHz. Two attempts at calibrating the 38 kHz transducer where attempted. No single-target detections were obtained on-axis during the first 38 kHz calibration experiment for a sphere with a theoretical TS of c. -33.5 dB. The acceptable TS detection range was therefore widened by 3 dB in the second experiment such that the theoretical TS detection limits were -33.5 dB ± 8 dB (standard range is usually the theoretical TS ± 5 dB). On-axis echoes were detected by the echosounder once the TS detection had been lowered, but no detections were possible in the side-lobes of two of the beam quadrants indicating an erroneous beam pattern (see Annex Figure 1). Resistance checks in the 38 kHz transducer cable revealed faults (open circuits) that were probably the main cause of the distorted beam pattern. The level of resistance in the cable varied with drop-keel position, but erroneous results were still obtained when the keel was in “survey” position.

Inspection of the echograms revealed distinct intermittent, step-changes in the performance of the 38 kHz transducer during the survey (Annex Figure 2). In this analysis, the intensity of the acoustic “blanking region” was compared throughout the survey for a standard 2 m analysis region close to the transducer face. As the sea-state was very calm throughout the survey, aeration effects in this zone were assumed to be negligible such that the “power” levels transmitted into the water during each ping could be compared (we assume here that the level of “noise” detected in the blanking region would be constant throughout the survey if the transducer transmitted the same level of “power” throughout the survey in calm weather). Distinct 3 dB reductions in echo sounder output were observed between the 14-16th October (1914 UTC) and the 18th-25th October (2229 UTC), indicating that the 38 kHz data was erroneous for much of the survey. The calibration report for the 38 kHz transducer is included in Annex Table 1.

Due to the problems with the 38 kHz data estimates of herring abundance and biomass were calculated from the fully-calibrated 18 kHz data. The 18 kHz calibration report is presented in Annex Table 2.

2.4 Survey protocols

2.4.1 Acoustic data acquisition

Acoustic data were observed and recorded onto the hard-drive of the processing unit using the equipment settings from previous surveys (Table 2). The “RAW files” were logged via a continuous Ethernet connection as “EK5” files to the vessels server and the ER60 hard drive as a backup in the event of data loss. In addition, as a further back up a hard copy was stored on DVD. Sonar Data’s Echoview® Echolog (Version

4) live viewer was used to display the echogram during data collection to allow the scientists to scroll through echograms noting the locations and depths of fish shoals. A member of the scientific crew monitored the equipment continually. Time and location (GPS position) data was recorded for each transect within each strata. This log was used to monitor the time spent off track during fishing operations and hydrographic stations plus any other important observations.

2.4.2 Echogram scrutinisation

Acoustic data was backed up every 24 hrs and scrutinised using Sonar data's Echoview® (V 4) post processing software. Partitioning of data into the categories shown below was largely subjective and was viewed by a scientist experienced in viewing echograms.

The NASC (Nautical Area Scattering Coefficient) values from each herring region were allocated to one of 4 categories after inspection of the echograms. Categories identified on the basis of trace recognition were as follows:

1. "Definitely herring" echo-traces or traces were identified on the basis of captures of herring from the fishing trawls which had sampled the echo-traces directly, and on large marks which had the characteristics of "definite" herring traces (i.e. very high intensity (red), narrow inverted tear-shaped marks either directly on the bottom or in midwater and in the case of spawning shoals very dense aggregations in close proximity to the seabed).

2. "Probably herring" were attributed to smaller echo-traces that had not been fished but which had the characteristic of "definite" herring traces.

3. "Herring in a mixture" were attributed to NASC values arising from all fish traces in which herring were thought to be contained, owing to the presence of a proportion of herring within the nearest trawl haul or within a haul that had been carried out on similar echo-traces in similar water depths.

4. "Possibly herring" were attributed to small echo-traces outside areas where fishing was carried out, but which had the characteristics of definite herring traces.

The "EK5" files were imported into Echoview for post-processing. The echograms were divided into transects. Echo integration was performed on a region which were defined by enclosing selecting marks or scatter that belonged to one of the four categories above. The echograms were analysed at a threshold of -70 dB and where necessary plankton was filtered out by thresholding at –65 dB.

The allocated echo integrator counts (NASC values) from these categories were used to estimate the herring numbers according to the method of Dalen and Nakken (1983).

The TS/length relationships used predominantly for the Celtic Sea Herring Survey are those recommended by the acoustic survey planning group based at 38 kHz (Anon, 1994):

Herring	TS =	20logL – 71.2 dB per individual (L = length in cm)
Sprat	TS =	20logL – 71.2 dB per individual (L = length in cm)
Mackerel	TS =	20logL – 84.9 dB per individual (L = length in cm)

Horse mackerel   TS = 20logL – 67.5 dB per individual (L = length in cm)

The TS length relationship used for gadoids was a general physoclist relationship (Foote, 1987):

Gadoids   TS = 20logL – 67.5 dB per individual (L = length in cm)

However, it was not possible to use the 38 kHz data due to problems with the 38 kHz transducer during the survey. Our alternative approach was to use the 18 kHz data to estimate herring abundance and biomass. There are currently no published TS-length relationships for herring at 18 kHz and ICES documentation offers little guidance on how to proceed in such scenarios. We therefore devised a simple TS model for herring at 18 kHz assuming that herring backscatter at both 38 kHz and 18 kHz is geometric (Fassler et al., 2007), such that herring TS follows the same TS = $20\log_{10}(L) - b_{20}$ relationship at these frequencies. Assuming this geometric relationship between the two frequencies, it should then be possible to offset the intercept value of the standard 38 kHz TS model (TS = $20\log_{10}(L) - 71.2$) according to the difference in frequency response of herring at 18 kHz. Our analyses revealed that herring backscatter is around 40% stronger at 18 kHz than at 38 kHz (frequency response = 1.4 ΔdB relative to 38 kHz; Saunders et al., 2010). This is strongly supported by extensive, ground-truthed acoustic data (c. 10 years) from herring surveys conducted by Institute of Marine Research (IMR), Norway (R. Korneliussen, personal communication), and by published data from multi-frequency studies on Atlantic herring backscattering properties (frequency response = 1.4 ΔdB; Fassler et al, 2007). Assuming that herring backscatter is 40% stronger at 18 kHz (frequency response = 1.4 ΔdB; which is 1.46 in 10log form), we calculated the 18 kHz TS model as:

(1) $TS_{18\ kHz} = 20\log_{10}(L) - 71.2 + 1.46$

(2) $TS_{18\ kHz} = 20\log_{10}(L) - 69.7$

Further details of this analysis are presented in Saunders et al. (2011).

2.4.3 Biological sampling

A single pelagic midwater trawl with the dimensions of 19m in length (LOA) and 6m at the wing ends and a fishing circle of 330 m was employed during the survey (Figure 22). Mesh size in the wings was 3.3 m through to 5 cm in the cod-end. The net was fished with a vertical mouth opening of approximately 9 m, which was observed using a cable linked “BEL Reeson” netsonde (50 kHz). The net was also fitted with a Scanmar depth sensor. Spread between the trawl doors was monitored using Scanmar distance sensors, all sensors being configured and viewed through a Scanmar Scanbas system.

All components of the catch from the trawl hauls were sorted and weighed; fish and other taxa were identified to species level. Fish samples were divided into species composition by weight. Species other than the herring were weighed as a component of the catch. Length frequency and length weight data were collected for each component of the catch. Length measurements of herring, sprat and pilchard were taken to the nearest 0.5 cm below. Age, length, weight, sex and maturity data were recorded for individual herring within a random 50 fish sample from each trawl haul, where possible.

All herring were aged onboard. The appropriate raising factors were calculated and applied to provide length frequency compositions for the bulk of each haul.

Decisions to fish on particular echo-traces were largely subjective and an attempt was made to target marks in all areas of concentration not just high density shoals. No bottom trawl gear was used during this survey. However, the small size of the midwater gear used and its manoeuvrability in relation to the vessel power allowed samples at or below 1m from the bottom to be taken in areas of clean ground.

2.4.4 Oceanographic data collection

Oceanographic stations were carried out during the survey at predetermined locations along the track. Data on temperature, depth and salinity were collected using a Seabird 911 sampler at 1m subsurface and 3m above the seabed. Coverage was broken down into 4 main hydrographic transects with CTD casts undertaken on selected transects in each of the target strata. Hydrographic stations were equally spread at 6-10nmi spacing on each transect where possible (Figure 1).

2.4.5 Marine mammal and seabird observations

During the survey an observer kept a daylight watch on marine mammal and seabird sightings from the crow's nest (18m above sea level).

During cetacean observations, watch effort was focused on an area dead ahead of the vessel and 45^{o} to either side using a transect approach. Sightings in an area up to 90^{o} either side of the vessel were recorded. The area was constantly scanned during these hours by eye and with binoculars. Ship's position, course and speed were recorded, environmental conditions were recorded every 15 minutes and included, sea state, visibility, cloud cover, swell height, precipitation, wind speed and wind direction. For each sighting the following data were recorded: time, location, species, distance, Bereing and number of animals (adults, juveniles and calves) and behaviour. Relative abundance (RA) of cetaceans was calculated in terms of number of animals sighted per hour surveyed (aph). RA calculations for porpoise, dolphin species and minke whales were made using data collected in ≤ Beaufort sea state 3. RA calculations for large whale species were made using data collected in ≤ Beaufort Sea state 5.

2.5 Analysis methods

2.5.1 Echogram partitioning

The analysis produced density values of numbers and biomass per nautical mile squared for each transect and mark category for each target species. These were then averaged over each stratum (weighted by transect length) and a biomass and abundance estimated by applying the stratum area and summing the strata estimates. Note that interconnecting inshore and offshore inter-transects were not included in the analysis. Total estimates and age and maturity breakdowns were calculated. Coefficient of variation (cv, standard error divided by the estimate) was estimated in the usual way after assuming that transects were identically distributed within a stratum and that they were statistically independent. CV were not reported for quantities that were unlikely to be used in a stock assessment (e.g., biomass of spent fish).

Biomass was calculated from numbers using length-weight relationships determined from the trawl samples taken during the survey for each of the analysis areas.

Herring weight (grams) = $0.00648 * L^{3.351}$ (L = length in cm)

Mackerel weight (grams) = $0.01118 * L^{3.032}$ (L = length in cm)

Sprat weight (grams) = $0.02404 * L^{3.192}$ (L = length in cm)

2.5.2 Abundance estimate

Total abundance, N_T, is given by $\sum_{m}^{Mark-types} N_{T,m}$, the sum over the total abundance by mark-types.

$$N_{T,m} = \sum_{s}^{strata} N_{m,s}$$

Suppressing the mark-type index, m, the stratum abundance is

$$N_s = area_s \sum_{l}^{transects} \bar{n}_{s,t} l_{s,t} \Big/ \sum_{j} l_{s,j}$$

,where *l* is the transect length and $\bar{n}$ is the transect mean abundance n.mi^{-2} which is given by

$$\sum_{j}^{track \cdot fragments} n_{s,t,j} d_{s,t,j} \Big/ l_{s,t}$$

, where d is the distance of the track fragment and $n_{s,t,j}$ is the mean abundance n.mi^{-2} for the jth track fragment.

Hauls are assigned with their own stratification that may not necessarily coincide with the acoustic strata, the conversion of NASC into mean density is done at the track fragment level, usually a 1 n.mi segment. The haul assigned, $h_{m,s,t,j}$, depends strongly on the mark-type (m) and since more than one school can be in a track fragment it needs to be specified. Since age and maturity length-keys are to be applied, the basic estimation is mean density by length bins. The $n_{s,t,j}$ is found by summing over the $n_{s,t,j}$.

$$n_{t,j,i} = \frac{NASC_{t,j}}{\bar{\sigma}_{h_{m,t,j}}} p_{i,h_{m,t,j}}$$

, where *i* indexes length bins, p_i is the proportion of herring in the i^{th} length bin, and is given by $\sum_{spe}^{species} \sum_{i} p_{spe,i} 10^{(a+b\log 10(L_{spe,i}))/10}$

, where $p_{spe,i}$ applies over all species considered in the haul, $L_{spe,i}$ is the length to use for the i^{th} length bin and the data comes from the haul (of combination of hauls) assigned, $h_{m,t,j}$. For non-mix mark-types, the later simplifies to

$$\sum_i p_{herring,i} 10^{(073+20\log 10(L_{herring,i}))/10}.$$

For biomass, a mean weight is also applied to the $n_{t,j,i}$ using the estimated regression relationship, a L_i^b.

For abundance by age and maturity, the abundance by length bin, $n_{t,j,i}$, is averaged over track fragments and then transects to give a strata (and mark-type) mean. The age and maturity keys are applied to the results.

$V_s = area_s^2 s_s^2 W_s$, where $W_s = \sum_l^{transects} l^2_{s,t} \Big/ (\sum_j l_{s,j})^2$ and s^2 is the sample variance. The variance for the total is the sum of strata variances.

The total biomass can be obtained directly from the track fragment mean biomass by $B_T = \sum_k^{track\cdot fragment} \overline{n}_k w_k$, where w_k is a factor that takes into account the factors for transect and strata averaging, i.e., $w_k = \dfrac{1n.mi}{l_{t_k}} \dfrac{l_{t_k}}{\sum_t^{stratum.s_k} l_{s_k,t}} area_{s_k} = \dfrac{1}{\sum_t^{stratum.s_k} l_{s_k,t}} area_{s_k}$

, where the 1 n.mi is the length of the track fragment. This ignores the mark-type since that is already accounted for in the $\overline{n}_k$. The $\overline{n}_k w_k$ is the biomass from a track fragment and they can then be used to map the biomass at a fine spatial scale.

Estimates are made for SSB, total abundance and biomass, abundance by age (ring counts), and abundance by age x length bins. A cv (based on strata standard error divided by the strata mean) is estimated for SSB, total abundance and biomass, and abundance by age.

3 Results

3.1 Celtic Sea herring stock

3.1.1 Herring biomass and abundance

Herring	Millions	Biomass (t)	% contribution
Total estimate			
Definitely	1348	148,183	96.4
Mixture	0	2	0.0
Probably	67	5,584	3.6
Total estimate	1415	153,769	100
SSB Estimate			
Definitely	917	118,929	97.7
Probably	24	2,789	2.3
Mixture	0	1	0.0
SSB estimate	941	121,719	100

Estimates of herring biomass and abundance detected at 18 kHz during the survey are summarised above. These estimates were derived from 1365 echotraces that were identified with the aid of 21 directed net hauls (Figure 2). Of the total number of echotraces attributed to herring, approximately 96% were in the 'Definitely herring' category and 4% occurred in the 'Probably herring' category (Table 11). There were very few mixed herring assemblages detected on the survey and this category represented less than 0.01% of the total biomass of herring. The majority of herring detected occurred in relatively large and discrete assemblages.

The overall herring biomass and abundance estimates were approximately 154,000 t (CV 19.4%) and 1415 million individuals (CV 19.2%), respectively. The overall SSB observed during the survey was around 122, 000 t (CV 19.4%), comprising an abundance of this component in the order of 941 million individuals.

Herring stock abundance and biomass estimates are further broken down by age, maturity status, size and strata in Tables 6-10. The length frequency data used to calculate herring target strength for the TSB and SSB estimates are presented in Table 4, and herring school counts by category and strata are presented in Table 11.

In general, the majority of herring biomass and abundance occurred in 3 strata (strata 9, 10 and 12), with stratum 10 contributing the greatest proportions to the TSB and SSB estimates (>75, 000 t; Table 11). Of the 19 strata surveyed, 8 contained no herring.

Herring within the 2 winter-ring group had the highest biomass and abundance (c. 56,000 t and 549 million individuals; Table 6 and 7) during the survey, with the 1 winter-ring group also relatively abundant (23, 000 t and 346 million individuals). There were also relatively high proportions of 3 and 4 winter-ringers (>11% by number and by biomass) estimated in the population, however, there was a distinctly low presence of the 0 winter-ring group (<1%).

3.1.2 Herring distribution

A total of 21 trawl hauls were carried out during the survey (Figure 2), with 18 hauls containing herring and 11 hauls containing >50% herring by weight of bulk catch (Table 3). In general, large and dense herring schools were predominantly concentrated close inshore in regions north of the 52° line between Helvick Head and Baginbun (Figure 3). There were relatively few large assemblages in the offshore regions and no herring were detected around the southwest corner of Ireland, expect for a dense school around Kerry Head.

The majority of herring schools detected throughout the survey occurred as either discrete, dense 'towers' protruding from the sea-bed (particularly around Baginbun), or extensive 'layers' that occupied around half of the water column (c. 10 m depth to the bottom) and were around 1-2 km in length at times (e.g. Helvick Head). Given the scale of these schools, there was a large proportion of herring that occurred off-transect and was not sampled during the survey. There were almost no mixed herring school assemblages on the survey, and only a few herring schools were detected in mid-water. Also, we frequently encountered herring that were pressed tight to the sea-bed in the more offshore sectors of the survey. These schools were difficult to detect acoustically (some targets being just a few ping-lengths off the bottom).

Overall, our observations accord well with reports from the commercial fishing fleet operating in the region in that relatively few catches of herring were obtained by the fleet in regions around Fastnet, Mine Head, Ballycotton and the Daunt. It should be noted that the spawning grid regions north of the 52° line are designated 'recovery' zones for herring and are off limits to the majority of the fishing fleet. There was a clear contrast in herring school morphology in this region compared to nearby spawning bay sectors (Ballycotton and the Daunt), where schools were considerably large, dense, continuous and undisturbed by fishing activity. Schools around Ballycotton and the Daunt were noticeably, small, fragmented and dispersed in comparison.

3.1.3 Herring stock composition

A total of 787 herring were aged during the survey. Also, over 5,426 herring were measured and approximately 1,820 length-weight measurements were obtained (Tables 3, 4 & 5). Herring age samples predominantly ranged from 0-6 winter-rings (Tables 6 & 7). The dominant age groups in terms of biomass were the 2 and 4 winter-ring fish that accounted for around 18-36% of the total TSB per group (c. 56,000 t and 29,000 t, respectively). Accordingly, these 2 cohorts were strong in terms of numerical abundance (2-group= 548.9 million, CV 19.3%; 4-group= 193.4 million). The population also contained a relatively high abundance of smaller herring (mean length: 20.5 cm) within the 1 winter-ring group (346.1 million, CV 22.4%) that comprised approximately 25% of the TSN and 15% of the TSB.

Our results showed that the majority (>66%) of the herring stock sampled was in a mature state of sexual development (Tables 8 & 9). However, no spawning individuals and no spent fish were encountered during the survey. The whole mature component of the herring stock (stages 3 to 8) sampled during the survey was in a pre-spawning state and was predominantly comprised of stage 4 individuals (>70% of the mature component).

3.2 Secondary pelagic species

During the scrutinisation process, acoustic data were categorised for secondary and tertiary target species (see section 2.4.2) based on information from trawl data. However, estimates of abundance and biomass are not reported here due to a loss of valid 38 kHz data. There were insufficient data to determine the frequency response of the other species encountered at 18 kHz, so it was not possible to calculate robust TS at 18 kHz for any secondary pelagic species. There are virtually no TS model values available in the literature (published or elsewhere) for the majority of pelagic fish species at 18 kHz. Species that we encountered regularly included sprat and mackerel.

Figure 4 shows the relative distribution of sprat encountered during the survey. Large concentrations of sprat were occurred around the Shannon, Kenmare Bay and off Tramore Bay. There were also concentrations of sprat around Ballycotton and Dingle Bay. Most of the sprat occurred close inshore and few schools were detected offshore. This general distribution pattern is similar to that reported by the commercial fishing fleet, particularly in regions around Ballycotton.

3.3 Oceanography

A total of 61 CTD stations were carried out during the survey. Surface plots of temperature and salinity are presented for the 5, 20, 40 and the >60 m depth profiles in Figures 5-8. In general, the hydrographic conditions in the Celtic Sea were similar to those observed in 2009. Temperature in the surface layers (above 5 m) was around 14-14.5 °C with surface salinity ranging between 34.9-35.1 ppt. Surface waters around the main spawning bays and southern coast regions were generally fresher than the off-shore sectors (Figure 5 and Figure 8), and there was a distinct surface anomaly off Waterford Harbour (Figure 5) where water was notably less saline than the surrounding water (c. 34.0 ppt). The water column below 5 m was relatively well-mixed in the inshore sectors of the Celtic Sea (13-15 ℃, c. 38.8 ppt), but well stratified further offshore (<11 ℃ and >35.0 ppt below 5 m). However, the more eastern regions of the Celtic Sea appeared slightly more stratified than in 2009, indicating the break down of the thermocline was later in this region in 2010. The impact of this on the underlying circulation pattern in the region is not clear from the data.

3.4 Marine mammal and seabird observations

Environmental data was collected at 447 stations. Sea state was ≤ 3 at 49.7% of environmental stations, ≤ 4 at 84.8% of stations and ≤ 5 at 95.1% of stations. Visibility was >5km at 83.2% of stations, 1–5km at 16.3% of stations and <1km at 0.4% of stations. Swell of 2m+ was recorded at 1.1% of stations. Rainfall was recorded at 3.1% of stations and fog was recorded at 7.2% of stations

3.4.1 Marine mammal sightings

98.2 hours of survey time were logged with 48.7% (47.8 hrs) of this at Beaufort sea state three or less; 83.9% (82.4 hrs) at Beaufort sea state four or less and 95.3% (93.6 hrs) at Beaufort sea state five or less. 105 sightings of at least six cetacean species, totalling 916 individuals were recorded (Table 14). Two seal sightings were also recorded.

Identified cetacean species were common dolphin (*Delphinus delphis*), harbour porpoise (*Phocoena phocoena*), Risso's dolphin (*Grampus griseus*), fin whale (*Balaenoptera physalus*), humpback whale (*Megaptera novaeangliae*) and minke whale (*Balaenoptera acutorostrata*). Two sightings of grey seal (*Halichoerus grypus*) were also made.

The distribution of these top-predator species is shown in Figures 9 and 10.

3.4.2 Seabird sightings

Daily species lists were made of all seabird species seen around the survey vessel. 16 seabird species were recorded during the survey: guillemot (*Uria aalge*); razorbill (*Alca torda*), gannet (*Morus bassanus*); fulmar (*Fulmarus glacialis*); kittiwake (*Rissa tridactyla*); black-headed gull (*Larus ridibundus*); lesser black backed gull (*Larus fuscus*); great black-backed gull (*Larus marinus*); herring gull (*Larus argentatus*); great skua (*Stercorarius skua*), long-tailed skua (*Stercorarius* longicaudus); parasitic skua (*Stercorarius parasiticus*); pomarine skua (Stercorarius *pomarinus*); sooty shearwater (*Puffinus griseus*); shag (*Phalacrocorax aristotelis*), storm petrel (*Hydrobates pelagicus*).

4 Discussion and Conclusions

4.1 Discussion

The aims and objectives of the survey were carried out as planned. Weather conditions were extremely favourable throughout the survey and all strata were sampled. Extensive net sampling was conducted on almost every significant acoustic target detected, regardless of subjective mark-type classification. Furthermore, net sampling was conducted on medium-intensity layers that were detected continuously for >8 nm. We can therefore hold a high degree of confidence in the echotrace scrutinization for herring. All of the scheduled CTD cast were completed, and the acoustic calibration was performed in favourable conditions in Dunmanus Bay.

Due to logistical factors our calibration experiments were performed at the end of the survey. The ER60 was last calibrated in June 2010 prior to this survey, and the echosounder was fully operational then and had not been used since. However, following our October survey it was noted that there was a fault with the 38 kHz transducer cable resulting a distorted beam pattern at this frequency. As a consequence, the whole 38 kHz data stream was deemed unsuitable for assessment purposes. We therefore adopted an alternative approach using fully-calibrated 18 kHz data to estimate herring abundance for the assessment models. The use of 18 kHz data (and our 18 kHz TS model) for such purposes is intrinsically valid, but current ICES assessment protocols are overtly dependent on the 38 kHz approach and there is presently no available guidance on how 18 kHz data might be used. For example, the Celtic Sea herring acoustic time-series used in the assessment is all based on 38 kHz data and it is not clear how much estimates of herring at 18 kHz vary from those calculated at 38 kHz. To our knowledge, there have been no published studies to quantify the level of variation between these two acoustic frequencies. We therefore compared 18 and 38 kHz-derived herring abundance estimates from the 2009, 2008 and 2007 Celtic Sea Herring Surveys to gain some insight into the level of variation between 18 and 38 kHz (Table 13; see Saunders et al., 2011 for more details). Our results showed only a c. 2-7% difference in biomass and abundance estimates at the two frequencies, suggesting that the 2010 estimates at 18 kHz are robust and suitable for the assessment models. Furthermore, there were no significant difference ($P>0.05$; Students t-test) in the acoustically-derived numbers-at-age estimates at 18 and 38 kHz for the previous two surveys. We can therefore hold a high level of confidence in the results presented here. Further analyses of the Celtic Sea herring survey time-series are currently ongoing to corroborate our initial findings.

The 2010 estimate of herring biomass is around 34, 000 t greater than that observed during the 2009 survey. The estimate is also the highest observed in the Celtic Sea area during the c. 9 year acoustic survey time-series that has been used in the assessment procedure. There was also a substantial increase in SSB between 2009 and 2010 (c. 34%). The results presented here corroborate the high biomass observed during the 2008 (93,319 t TSB and 90, 855 t SSB) and 2009 (119,083 t TSB and 90, 937 t

SSB) surveys, and suggest that the herring stock in the Celtic Sea is continuing on an upward trend. For example, this is the fifth consecutive year that the acoustic estimate has increased substantially (2005-2010). Throughout the species distributional range in the northeast Atlantic, herring stocks are generally considered to be in a state of decline with little signs of recovery in recent years. Our acoustic estimates suggest that the Celtic Sea herring stock might be countering this trend and that there is a tendency towards a recovery in the overall stock, with several strong year classes and evidence of recruitment to older year classes in the population. These preliminary trends in stock recovery are particularly interesting considering that herring are thought to be on the southern-most margins of its distributional limit in the Celtic Sea. Another interesting point to note is that the spawning bays to the north of 52° are currently off limits to the RSW component of the fishing fleet as a recovery measure for the spawning Celtic Sea herring stock. Schools within this zone were markedly larger, denser and less-scattered than those found in areas frequently disturbed by routine fishing activity. It is possible that this exclusion zone has had a positive effect on the Celtic Sea herring stock, enabling larger numbers of herring to congregate undisturbed and spawn greater numbers of new recruits into the population. However, herring distribution of abundance and population dynamics are highly variable in space and time, and further data are required to substantiate preliminary trends in stock recovery, and to address any potential causal mechanisms.

The distribution of herring was similar to that observed in the 2009 survey in that the majority of herring biomass was situated predominantly inshore areas around, Helvick Head, Tramore Bay and Baginbun. A notable difference between the 2009 and 2010 surveys was that there was very few mixed herring assemblages detected on the 2010 survey. In 2009, small herring and mackerel (c. 15 cm length) assemblages were frequently detected, particularly around the more off-shore sectors. Few small herring and mackerel were observed on this year's survey. Overall, our observations of herring and sprat distribution matched those of the commercial fishing fleet in the regions open to herring fishing by RSW vessels. The commercial fleet reported mixed fishing success in most regions covered by our survey, and many hauls often contained sprat. Communications with the fishing fleet were aided greatly by the presence of an onboard observer representing the Irish South and West Fish Producers Organisation.

Throughout the survey, all herring assemblages were detected well within the confines of the survey boundaries. There were no instances of large herring schools occurring on the fringes of the survey grid. Furthermore, all the major herring cohorts were picked up in the biological samples collected on the survey. It is therefore becoming increasing apparent that the Celtic Sea Herring Acoustic Survey design is rigorous, particularly in the southwest region that constitutes the main survey sector. However, further attention should be placed on the SE corner of the grid. Historic information shows that herring are present in the Smalls area (Burd and Bracken, 1965) and future surveys should investigate this area. Consideration might also be given to the sampling intensity around the southwestern sector of the survey (Strata 1-7), as very little herring has been detected here in the past four surveys. Between 2007-2010, strata 1-7 have contributed less than 1% to the overall herring biomass/abundance estimates on each survey and herring echotraces are seldom detected (Table 6). However, historical data suggests that the region has been important for herring in the past, so this sector would probably need some level of monitoring during the survey. The region is also important for sprat and there is increasing evidence from commercial sampling that the current survey design is monitoring sprat abundance fairly robustly in the region. Given that fisheries surveys are now being geared towards more ecosystem-based monitoring, the current survey design might be the most suitable approach. Also, standardised survey grid and fixed sampling times are essential prerequisites for quantifying inter-annual variations in herring abundance and population dynamics.

The presence of herring on the main autumn spawning grounds can extend for up to 3 months and overlaps with the arrival of the smaller winter spawning component. During this time biomass on the spawning grounds is replenished by several waves of migration. The survey is designed to contain the stock within its boundaries. As a result the 2010 biomass is likely to contain an un-quantified proportion of the winter spawning component. As no survey is currently undertaken on the winter stock component, it is impossible to determine the contribution of each component between years.

The hydrographic conditions encountered during this year's survey were similar to those observed during 2009. Surface water (0-40 m) temperature in the Celtic Sea was around 14 °C, with surface water temperatures slightly higher in the more eastern and off shore sectors (c. 15 °C). In generally, the water column was slightly more stratified in eastern sector than in 2009. There was a distinct salinity anomaly off Waterford Harbor at 5 m where the water was considerably fresher (c. 34.0 ppt) than surrounding regions. The water temperature in the inshore regions at 60 m was around 13 °C, which was cooler than that observed in 2009 (c. 14.5 °C). Overall, the trend in mean annual temperature in the Celtic Sea is increasing. A preliminary look at sea surface temperature in October across years (1998-2009) shows no correlation between cooler years and increased biomass. Herring are known to use temperature as one of the cues for the onset of spawning migrations. However, there are likely to be a number of complex physical and biological factors controlling such behavior and temperature alone cannot be used to model herring abundance accurately.

4.2 Conclusions

- A high quantity of herring was observed in the Celtic Sea area during the 2010 acoustic survey. The TSB, TSN and SSB was 153,769 t (CV 19.4%), 1415 million individuals (CV 19.2%) and 121, 719 t (CV 19.4%), respectively. The TSB is the highest observed to date.
- Estimates of herring abundance were calculated at 18 kHz due to a loss of 38 kHz data. Analyses of past data showed a high degree of overlap between 18 and 38 kHz-derived estimates of herring abundance (2-7% difference), suggesting that the 2010 estimates are robust.

- Standardized survey design and fixed sampling times are enabling herring cohorts to be tracked. The herring population was sampled effectively during the survey and there is some evidence of successful recruitment of the 2007 and 2005 year classes.

- The largest herring schools were predominantly distributed inshore around the spawning grounds between Helvick Head and Baginbun. However, almost all mature fish were in a pre-spawning state (stage 4 and 5) and there were no spent individuals.

- The most widely encountered secondary species was sprat. However, it was not possible to quantify sprat abundance due to uncertainties in sprat TS at 18 kHz.

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5 Tables and Figures

Table 1. Survey Strata details. Celtic Sea herring acoustic survey, October 2010.

Strata no.	Strata name	Survey type	Transect type	Total transects	Active transects	Transect spacing	Total transect distance (nmi)	Strata area (nmi2)
1 (a,b)	SW Shannon	Broad scale	Parallel	26	14	4	192	727
2	Inside Shannon	Broad scale	Zigzag	7	7	\	41	39
3	Dingle	Broad scale	Zigzag	9	9	\	69	99
4 (a,b)	SW corner	Broad scale	Parallel	15	8	4	179	548
5	Kenmare	Broad scale	Zigzag	7	7	\	43	61
6	Bantry	Broad scale	Zigzag	8	7	\	35	34
7	Dunmanus	Broad scale	Zigzag	7	7	\	26	9
8	Mizen area	Broad scale	Parallel	27	14	4	310	770
9	Offshore CS	Broad scale	Parallel	63	32	2	1002	1932
10 (a,b,c,d,e)	Inshore CS	Broad scale	Parallel	61	34	2	631	1106
11	Baginbun	Spawning grid	Parallel	17	9	1	67	29
12	Tramore	Spawning grid	Parallel	31	16	1	110	85
13	Waterford Hbr	Broad scale	Zigzag	4	4	\	11	4
14	Ballycotton	Spawning grid	Parallel	32	16	1	115	104
15	Daunt	Spawning grid	Parallel	25	13	1	80	69
16	Stags	Spawning grid	Parallel	9	5	1	97	16
17	Dingle_S	Spawning grid	Parallel	11	6	1	24	9
18	Dingle_N	Spawning grid	Parallel	11	6	1	22	7
19	Kerry Head	Spawning grid	Parallel	23	12	1	136	61
			Total	393	226		3192	5705.98

Table 2. Settings for the Simrad ER60 echosounder at 18 kHz, employed during the Celtic Sea herring acoustic survey, October 2010.

Echo sounder:	Simrad ER 60
Frequency:	18 kHz
Transducer:	ES 18-11- Serial 2043
Absorption Coefficient:	0.024 dB/Km (manual)
Pulse length:	1.024 m/s
Bandwidth:	1.19 KHz
Transmitting Power:	2000 W (Max)
Angle Sensitivity:	13.9 dB
2- way beam angle:	-20.60°
Gain:	23
SA Correction:	-0.65
3 dB Beam W Alongship:	10.37°
Athwartship:	10.3°
Max Range:	500m

Note: Calibration report available (18 and 38KHz) in Appendix

Table 3. Catch table from directed net hauls during the Celtic Sea herring acoustic survey, October 2010.

No.	Date	Lat. N	Lon. W	Time	Bottom (m)	Target (m)	Bulk Catch (Kg)	Herring %	Mackerel %	Scad %	Sprat %	Pilchard %	Others* %
1	09.10.10	52 35.37	010 2.371	17:05	85	11	9.1	0.0	4.2	0.0	79.2	0.0	16.5
2	13.10.10	51 13.08	008 14.02	17:49	96	4	228.3	94.0	5.5	0.0	0.0	0.0	0.5
3	14.10.10	51 07.50	008 04.35	03:50	95	0	250	99.7	0.0	0.0	0.0	0.0	0.3
4	14.10.10	51 10.08	008 00.79	09:16	98	8	1,000	99.5	0.2	0.0	0.1	0.0	0.2
5	15.10.10	51 23.33	007 41.81	05:35	83	0	55.3	73.7	12.5	0.0	9.1	0.0	4.6
6	15.10.10	51 29.09	007 38.68	12:27	80	6	2,500	99.4	0.4	0.0	0.1	0.0	0.0
7	15.10.10	51 09.04	007 35.77	17:00	91	2	22.2	3.4	14.0	0.0	56.6	0.0	25.8
8	16.10.10	51 27.89	007 23.11	09:02	79	6	139.6	1.0	4.6	0.0	94.4	0.0	0.0
9	16.10.10	51 24.05	007 23.24	10:46	82	10	210	0.7	45.0	0.0	54.3	0.0	0.0
10	17.10.10	51 28.98	007 0.14	09:18	74	8	60.3	4.2	74.4	0.0	18.3	0.1	3.2
11	17.10.10	51 46.11	006 59.96	12:40	70	2	160.3	0.7	30.0	0.0	69.0	0.0	0.4
12	17.10.10	51 42.99	006 53.72	19:01	69	6	169.9	0.4	22	0.0	59.40	0.0	18.8
13	18.10.10	52 05.60	006 42.35	06:06	30	0	0	0.0	0.0	0.0	0.0	0.0	0.0
14	18.10.10	52 00.83	006 46.10	09:32	48	0	300	97.7	2.0	0.0	0.0	0.0	0.2
15	18.10.10	52 01.02	006 51.16	14:53	51	0	15,000	98.9	0.0	0.0	0.0	1.1	0.0
16	19.10.10	52 01.99	007 05.97	03:29	45	0	12,000	95.5	3.6	0.0	0.0	0.9	0.0
17	19.10.10	52 05.16	007 14.45	15:46	36	0	15,000	89.1	9.7	0.0	0.0	1.2	0.0
18	20.10.10	52 06.33	007 24.01	23:18	22	0	12,000	97.7	2.2	0.0	0.0	0.1	0.0
19	20.10.11	51.48.838	7.39.95	11:47	62	0	91.082	0.0	3.0	0.0	96.8	0.0	0.1
20	23.10.10	51 38.25	008 29.38	02:30	18	0	3,000	100.0	0.0	0.0	0.0	0.0	0.0
21	24.10.10	52 01.63	010 13.43	03:02	40	0	75.427	0.6	92.3	4.3	0.0	0.0	2.6

Table 4. Length-frequency (%) of herring hauls used for calculating ‘definitely’ and ‘probably’ abundance categories. Celtic Sea herring acoustic survey, October 2010.

Length (cm)	Haul 2	Haul 3	Haul 4	Haul 6	Haul 14	Haul 15	Haul 16	Haul 17	Haul 18	Haul 20
15					1					1
15.5					1					
16										
16.5										1
17										
17.5										
18					2					
18.5					4				1	1
19				2	14			1	1	6
19.5				5	32	1		1	4	11
20				6	23	1		4	8	12
20.5				5	12	3		5	7	16
21		1	1	7	8	2		7	5	9
21.5		1	1	5	3	9	1	6	5	9
22		1	4	6	1	11	1	7	5	10
22.5		11	8	5		8	3	6	3	8
23	2	10	8	7		11	8	7	3	4
23.5	5	20	9	7		10	3	5	4	2
24	6	9	12	7		9	12	9	4	1
24.5	11	15	16	8		10	9	5	8	1
25	18	8	12	7		7	12	7	5	2
25.5	14	7	8	5		5	10	7	5	1
26	12	6	7	8		7	11	8	9	1
26.5	13	6	7	5		5	12	7	10	2
27	12	4	5	3		2	9	4	7	2
27.5	5	1	1	2		1	5	2	3	1
28	1	1	1	1			3		1	1

Table 5. Herring Age length key from combined trawl samples. Celtic Sea herring acoustic survey, October 2010.

Length	0	1	2	3	4	5	6	7	8
12.5	1								
13	2								
13.5	23								
14	34								
14.5	58								
15	61								
15.5	32								
16	2								
16.5	3								
18		3							
18.5		5							
19		7							
19.5		26	3						
20		26	8						
20.5		20	6						
21		12	10						
21.5		10	16	4					
22		9	13		1				
22.5		4	25	2					
23			18	4					
23.5			29	4					
24			29	5	1				
24.5			34	13	2				
25			26	10	6	2			
25.5			12	17	18	1			
26			2	10	24	2	4	1	
26.5			1	2	13	5	8		
27					12	11	11	2	
27.5					2	4	9		
28					1	1	1		1
28.5				1			1		
29							1		
Total	**216**	**122**	**232**	**72**	**80**	**26**	**35**	**3**	**1**
%	27.45	15.50	29.48	9.15	10.17	3.30	4.45	0.38	0.13

Table 6. Total biomass (000's tonnes) of herring at age (winter rings), by strata as derived from acoustic estimate of abundance**.** Celtic Sea herring acoustic survey, October 2010.

Strata	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**Total**
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0	0.1	0.1	0	0	0	0	0	0	0.3
9	0	0.8	4.7	1.7	2.1	0.7	0.9	0.1	0	11.1
10	0.1	14.9	32.3	12	19	7.1	10.1	0.7	0.4	96.5
11	0	0	0.1	0	0	0	0	0	0	0.1
12	0	2.3	13.9	5.1	6.9	2.4	3.5	0.2	0.2	34.4
13	0	0	0	0	0	0	0	0	0	0
14	0	0.6	0.6	0.1	0.1	0.1	0.1	0	0	1.6
15	0	3.1	2.9	0.4	0.4	0.2	0.3	0	0	7.4
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0	1	0.9	0.1	0.1	0.1	0.1	0	0	2.4
Total	0.1	22.7	55.6	19.5	28.7	10.5	15	1.1	0.6	153.8
%	0.1	14.8	36.1	12.7	18.6	6.8	9.8	0.7	0.4	100

Table 7. Herring abundance (millions) at age (winter rings), by strata as derived from acoustic estimate of abundance. Celtic Sea herring acoustic survey, October 2010.

Strata	0	1	2	3	4	5	6	7	8	Total
1	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0
8	0.04	1.70	1.23	0.14	0.11	0.05	0.06	0	0	3.34
9	0.21	12.48	43.67	13.92	14.19	4.43	5.62	0.46	0.19	95.17
10	2.65	229.77	319.68	94.63	127.27	43.81	61.54	4.56	1.93	885.84
11	0	0.15	0.70	0.17	0.13	0.03	0.04	0.00	0.00	1.22
12	0	30.75	131.78	40.71	46.55	14.90	20.95	1.46	0.80	287.90
13	0	0	0	0	0	0	0	0	0	0
14	0.21	8.74	6.76	0.97	0.93	0.37	0.51	0.03	0.03	18.54
15	1.21	47.31	34.12	4.02	2.92	1.26	1.75	0.10	0.12	92.80
16	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0
19	0.39	15.25	11.00	1.30	0.94	0.41	0.57	0.03	0.04	29.91
Total	4.70	346.15	548.94	155.86	193.03	65.24	91.04	6.65	3.11	1414.71
%	0.33	24.47	38.80	11.02	13.64	4.61	6.44	0.47	0.22	100.00
Cv (%)	44.70	22.40	19.30	20.50	22.60	23.60	23.60	23.60	28.20	19.20

Table 8. Herring biomass (000's tonnes) at maturity by strata. Totals do not account for the "possibly" herring classification. Celtic Sea herring acoustic survey, October 2010.

Strata	Immature	Mature	Spent	Total
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	0.2	0.1	0	0.3
9	1.2	9.9	0	11.1
10	20.6	75.9	0	96.5
11	0	0.1	0	0.1
12	3.7	30.7	0	34.4
13	0	0	0	0
14	0.8	0.8	0	1.6
15	4.2	3.2	0	7.4
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	1.4	1	0	2.4
Total	32	121.7	0	153.8
%	20.8	79.2	0	100

Table 9. Herring abundance (millions) at maturity by strata. Totals do not account for the possibly herring classification. Celtic Sea herring acoustic survey, October 2010.

Strata	Immature	Mature	Spent	Total
1	0	0	0	0
2	0	0	0	0
3	0	0	0	0
4	0	0	0	0
5	0	0	0	0
6	0	0	0	0
7	0	0	0	0
8	2.29	1.05	0	3.34
9	17.70	77.47	0	95.17
10	308.88	576.95	0	885.84
11	0.25	0.97	0	1.22
12	48.90	239.00	0	287.90
13	0	0	0	0
14	11.76	6.79	0	18.54
15	63.56	29.24	0	92.80
16	0	0	0	0
17	0	0	0	0
18	0	0	0	0
19	20.49	9.42	0	29.91
Total	473.82	940.89	0	1414.71
%	33.49	66.51	0	100.00

Table 10. Herring length at age (winter rings) as abundance (millions) and biomass (000's tonnes). Celtic Sea herring acoustic survey, October 2010.

Length	0	1	2	3	4	5	6	7	8	Abund (mill)	Bio ('000t)	Mn wt (g)
13	0.48									0.48	0.01	15.20
14	0.48									0.48	0.01	19.30
14.5	0.48									0.48	0.01	21.70
15	1.69									1.69	0.04	24.20
15.5	0.48									0.48	0.01	27.00
16.5	1.11									1.11	0.04	33.10
18		2.78								2.78	0.12	43.90
18.5		9.43								9.43	0.45	48.10
19		29.96								29.96	1.57	52.50
19.5		67.07	7.70							74.77	4.27	57.10
20		71.01	21.81							92.82	5.76	62.00
20.5		68.12	20.46							88.58	5.96	67.30
21		35.65	29.76							65.41	4.76	72.80
21.5		24.72	39.57	9.87						74.17	5.83	78.60
22		29.35	42.40		3.23					74.98	6.36	84.80
22.5		8.07	50.43	4.07						62.57	5.71	91.30
23			57.42	12.78						70.19	6.89	98.10
23.5			59.16	8.14						67.30	7.09	105.30
24			69.96	12.07	2.45					84.48	9.53	112.80
24.5			69.19	26.42	4.09					99.69	12.04	120.70
25			52.41	20.13	12.06	3.99				88.60	11.43	129.00
25.5			19.93	28.21	29.89	1.67				79.70	10.97	137.70
26			5.01	24.86	59.53	5.01	9.92	2.45		106.80	15.67	146.70
26.5			3.71	7.52	48.85	18.76	30.10			108.94	17.02	156.20
27					24.95	22.93	22.93	4.20		75.01	12.46	166.10
27.5					4.86	9.76	21.94			36.57	6.45	176.40
28					3.11	3.11	3.11		3.11	12.45	2.33	187.20
28.5				1.78			1.78			3.56	0.71	198.40
29							0.83			0.83	0.18	210.10
29.5							0.42			0.42	0.09	222.30
SSN (mil)	0	33.15	408.82	146.62	191.26	65.24	91.04	6.65	3.11	940.89		
SSB('000t)	0	2.75	44.57	18.97	28.51	10.53	15.04	1.06	0.58		121.72	
Mn wt (g)	24.90	65.70	101.20	124.90	148.50	161.30	165.20	159.00	187.20			
Mn.length(cm)	15.30	20.50	23.40	24.90	26.30	27.00	27.20	26.90	28.20			

Table 11. Herring biomass and abundance by survey strata. Celtic Sea herring acoustic survey, October 2010.

Stratum	No. tran-sects	No. schools	Def schools	Mixed schools	Prob schools	Zero transects (%)	Def. biomass	Mixed Biomass	Prob. Biomass	Biomass ('000t)	SSB ('000t)	Abundance (mill)
1	14	0	0	0	0	100	0	0	0	0	0	0
2	6	0	0	0	0	100	0	0	0	0	0	0
3	9	0	0	0	0	100	0	0	0	0	0	0
4	8	0	0	0	0	100	0	0	0	0	0	0
5	7	0	0	0	0	100	0	0	0	0	0	0
6	7	0	0	0	0	100	0	0	0	0	0	0
7	5	0	0	0	0	100	0	0	0	0	0	0
8	15	2	0	0	2	93	0	0	0.3	0.3	0.1	3.336
9	32	594	539	0	55	44	10.3	0	0.9	11.1	9.9	95.168
10	34	193	182	2	9	56	96	0	0.5	96.5	75.9	885.836
11	9	1	1	0	0	89	0.1	0	0	0.1	0.1	1.224
12	17	418	418	0	0	0	34.4	0	0	34.4	30.7	287.9
13	5	0	0	0	0	100	0	0	0	0	0	0
14	16	33	0	0	33	69	0	0	1.6	1.6	0.8	18.542
15	13	117	117	0	0	31	7.4	0	0	7.4	3.2	92.795
16	5	0	0	0	0	100	0	0	0	0	0	0
17	6	0	0	0	0	100	0	0	0	0	0	0
18	6	0	0	0	0	100	0	0	0	0	0	0
19	12	1	0	0	1	92	0	0	2.4	2.4	1.0	29.907
Total	226	1359	1257	2	100	70	148.2	0	5.6	153.8	121.7	1414.708
Cv (%)	-	-	-	-	-	-	-	-	-	19.4	19.4	19.2

Table 12. Celtic Sea and VIIj Herring acoustic survey time series. Abundance (millions), TSN and SSB (000's tonnes). Age in winter rings. *Note 2009/2010 values are derived from 18 kHz data.

	1995	**1996**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**
	1996	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**
0	202	3	-	0	-	25	40	0	24	-	2	-	1	99	239	5
1	25	164	-	30	-	102	28	42	13	-	65	21	106	64	381	346
2	157	795	-	186	-	112	187	185	62	-	137	211	70	295	112	549
3	38	262	-	133	-	13	213	151	60	-	28	48	220	111	210	156
4	34	53	-	165	-	2	42	30	17	-	54	14	31	162	57	193
5	5	43	-	87	-	1	47	7	5	-	22	11	9	27	125	65
6	3	1	-	25	-	0	33	7	1	-	5	1	13	6	12	91
7	1	15	-	24	-	0	24	3	0	-	1	-	4	5	4	7
8	2	0	-	4	-	0	15	0	0	-	0	-	1	-	6	3
9	2	2	-	2	-	0	52	0	0	-	0	-	0	-	1	-
Abundance	469	1338	-	656		256	681	423	183	-	312	305	454	769	1,147	1,414
SSB	36	151	-	100		20	95	41	20	-	33	36	46	90	91	122
CV	53	26	-	36		100	88	49	34	-	48	35	25	20	24	20
Design	AR	AR		AR		AR	AR	AR	AR		R	R	R	R	R	R

Table 13. Comparison of Biomass, SSB and abundance estimates calculated at 18 and 38 kHz for the 2009, 2008 and 2007 Celtic Sea Herring Acoustic Surveys. Units are: Abundance (millions of individual fish) SSB and Biomass ('000 t).

	18 kHz (CV%)		**38 kHz (CV%)**		**% difference**
2010					
Biomass	153.8	(19.4)	-	-	-
SSB	121.7	(20.5)	-	-	-
Abundance	1414.7	(19.2)	-	-	-
2009					
Biomass	119.5	(23.7)	119.1	(22.7)	0.3
SSB	93.0	(24.6)	90.9	(24.0)	2.3
Abundance	1122.3	(23.5)	1147.4	(23.1)	2.1
2008					
Biomass	91.9	(23.4)	93.3	(19.6)	1.5
SSB	90.6	(23.7)	90.9	(20.0)	0.3
Abundance	715.7	(22.2)	768.6	(19.2)	6.8
2007					
Biomass	54.2	(19.9)	53.2	(23.0)	1.9
SSB	45.6	(21.7)	46.4	(24.9)	1.7
Abundance	478.8	(18.8)	454.0	(21.6)	5.4

Table 14. Sightings, counts and group size ranges for cetaceans sighted during current survey. Celtic Sea herring acoustic survey, October 2009.

Species	No. Sightings	No. Individuals	Range of Group Size
Common dolphin	73	774	1-65
Harbour porpoise	2	13	5-8
Risso's dolphin	1	3	-
Fin Whale	3	6	1-3
Humpback Whale	1	2	-
Minke whale	4	4	-
*UnID baleen whale (blow)**	4	7	1-4
UnID Dolphin	15	107	1-50
Grey seal	2	2	-

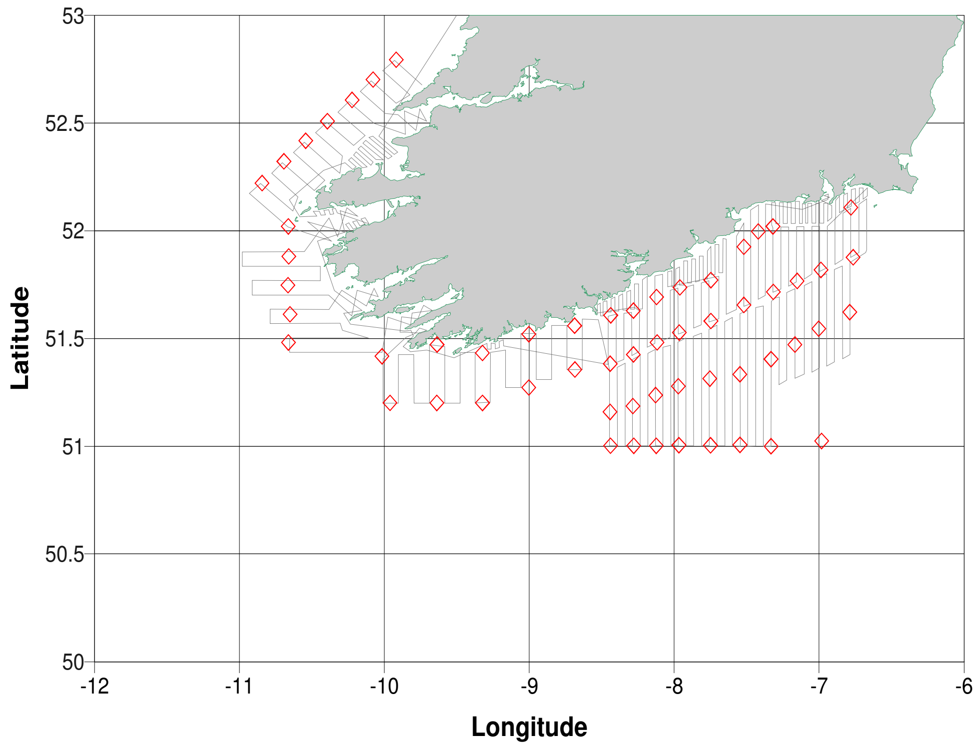


Figure 1. Cruise track (grey line) and CTD positions during the Celtic Sea herring acoustic survey, October 2010.

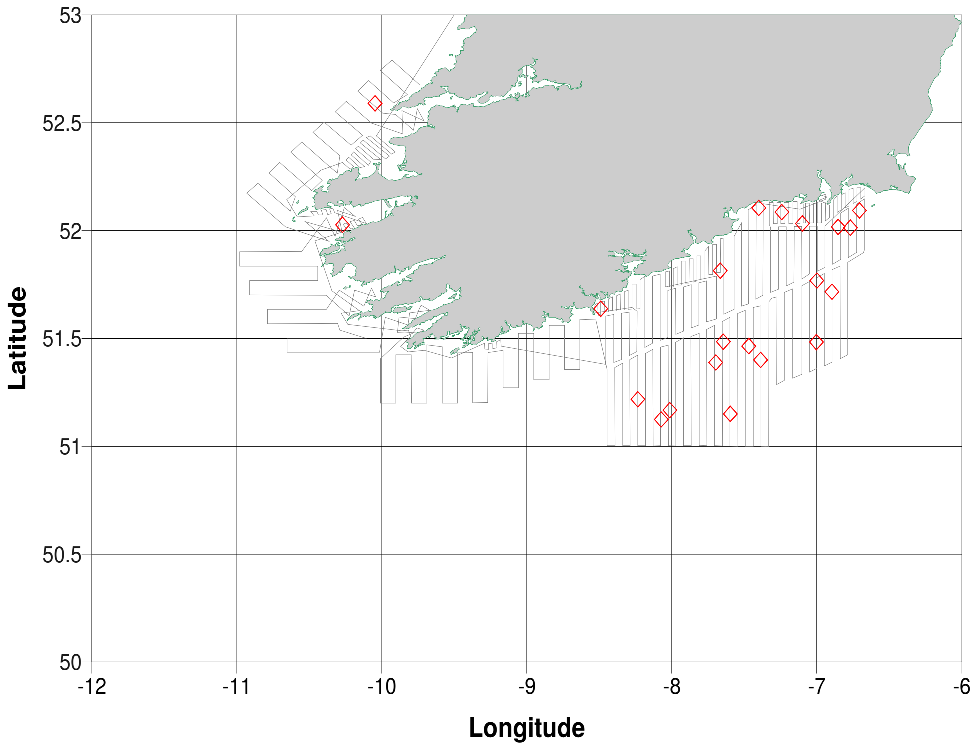


Figure 2. Haul positions. Celtic Sea herring acoustic survey, October 2010.

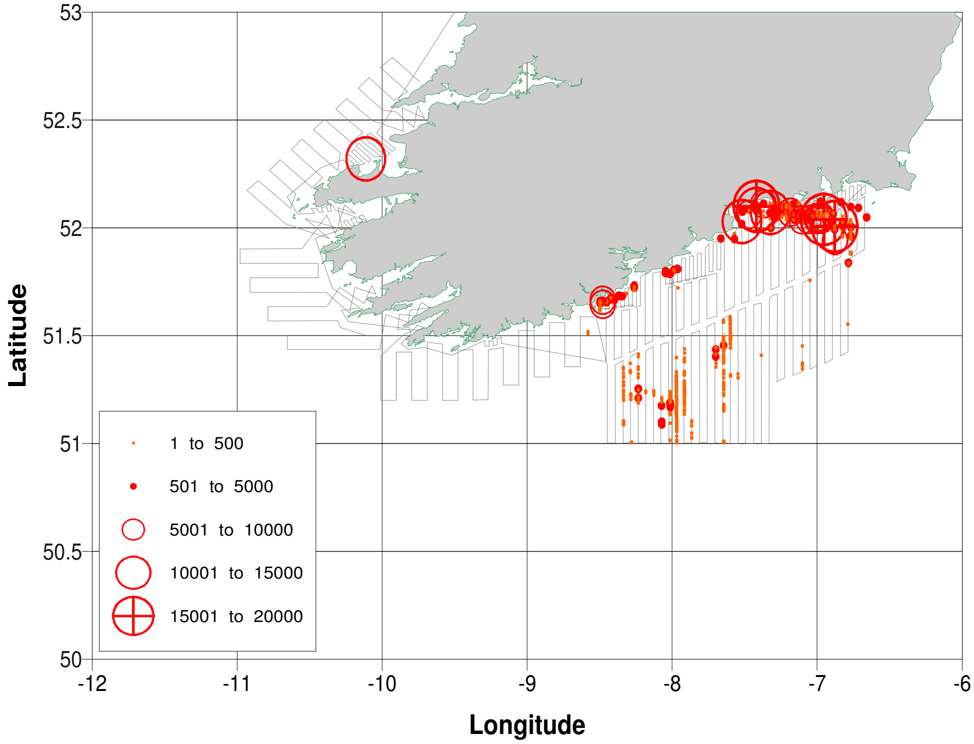


Figure 3. Weighted herring NASC (Nautical area scattering coefficient) plot showing the distribution of "definitely" and "probably" categories. Celtic Sea herring acoustic survey, October 2010.

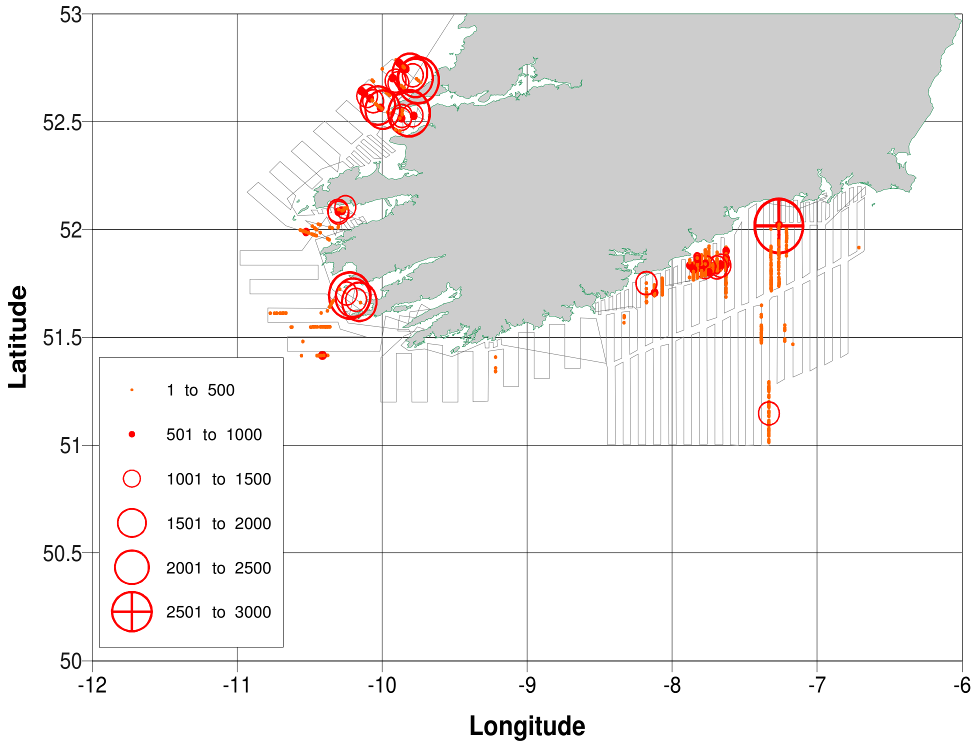
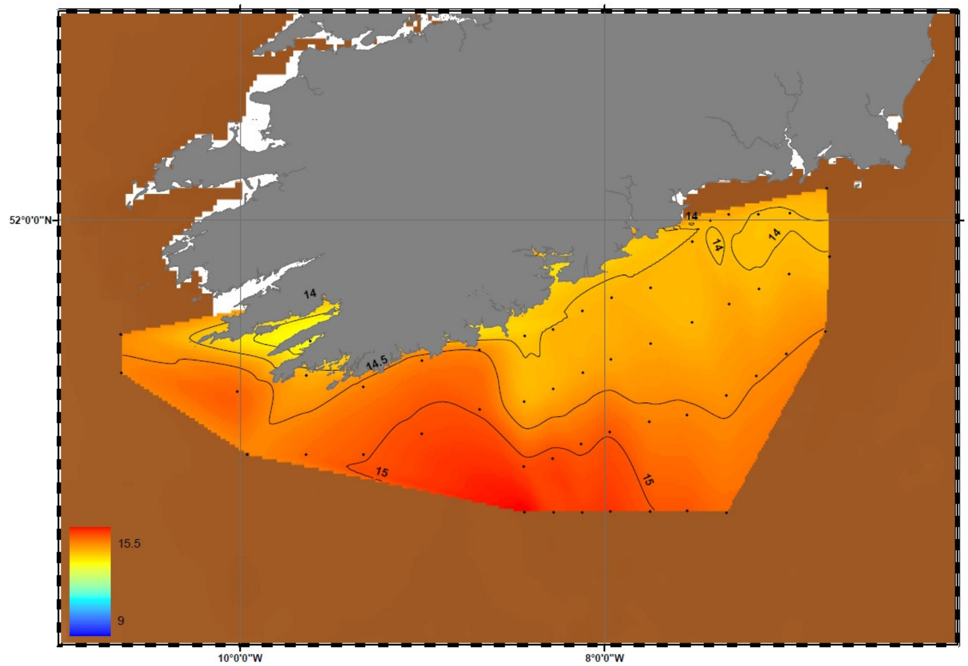


Figure 4. Weighted Sprat NASC (Nautical area scattering coefficient) plot showing the distribution of "definitely" and "probably" categories. Celtic Sea herring acoustic survey, October 2009. Note: the plot is based on 18 kHz data.



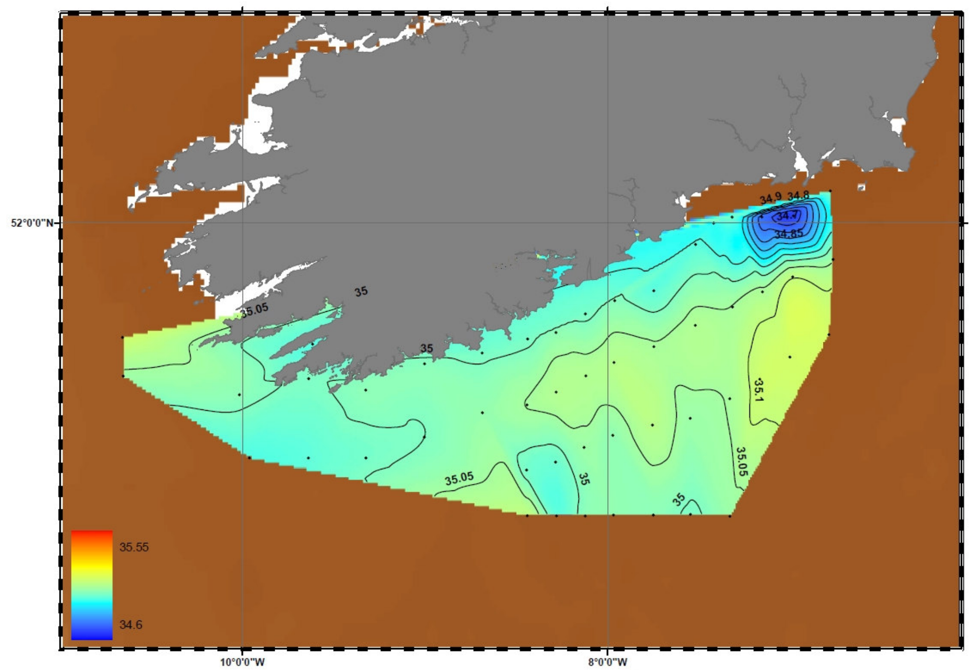


Figure 5. Surface plots of temperature (above) and salinity (below) at 5 m from combined CTD cast data. Celtic Sea herring acoustic survey, October 2010.

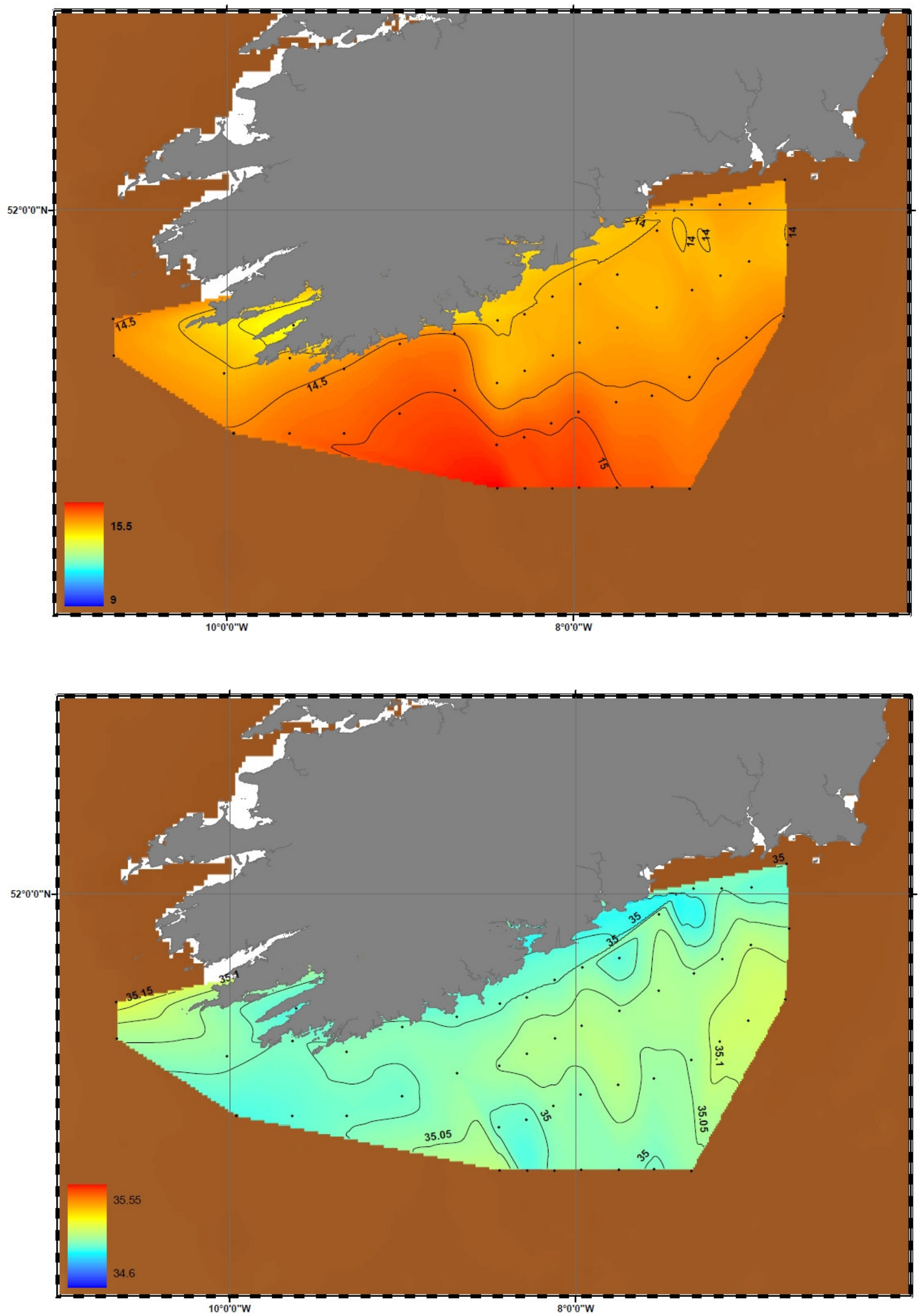


Figure 6. Surface plots of temperature (above) and salinity (below) at 20 m from combined CTD cast data. Celtic Sea herring acoustic survey, October 2010.

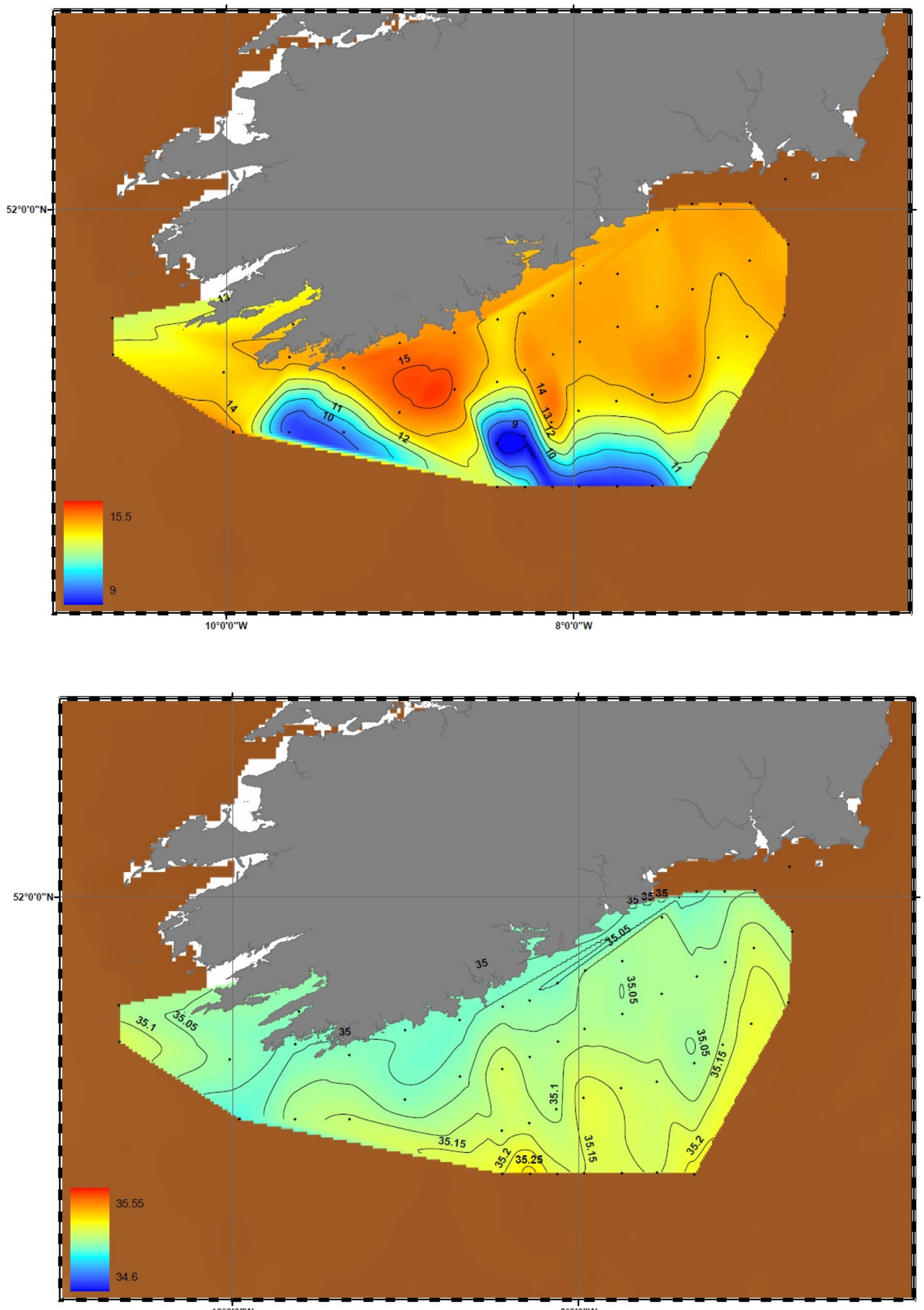
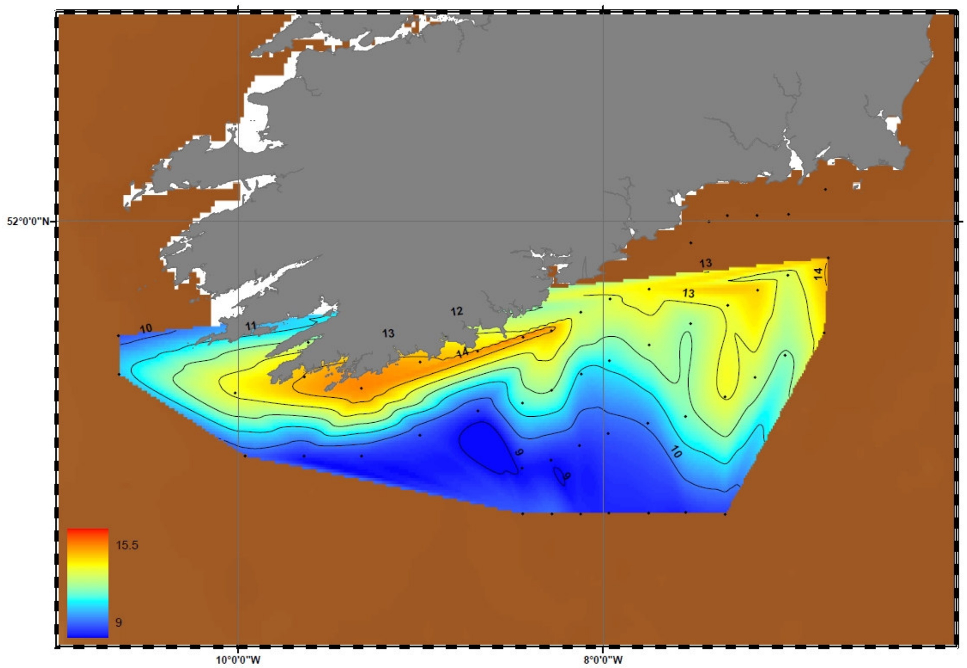


Figure 7. Surface plots of temperature (above) and salinity (below) at 40m from combined CTD cast data. Celtic Sea herring acoustic survey, October 2010.



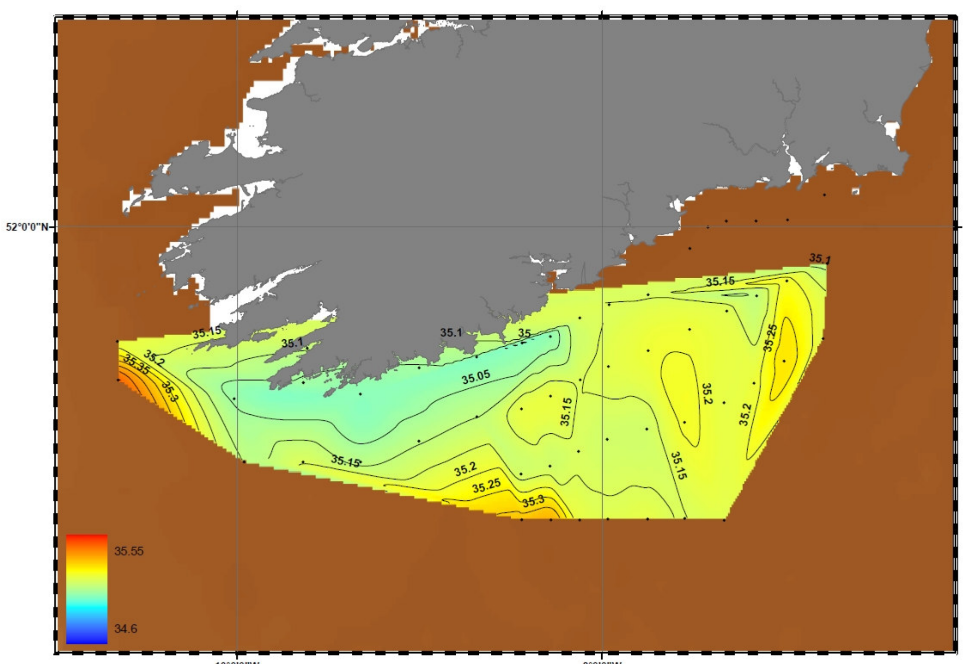


Figure 8. Surface plots of temperature (above) and salinity (below) at >60 m from combined CTD cast data. Celtic Sea herring acoustic survey, October 2010.

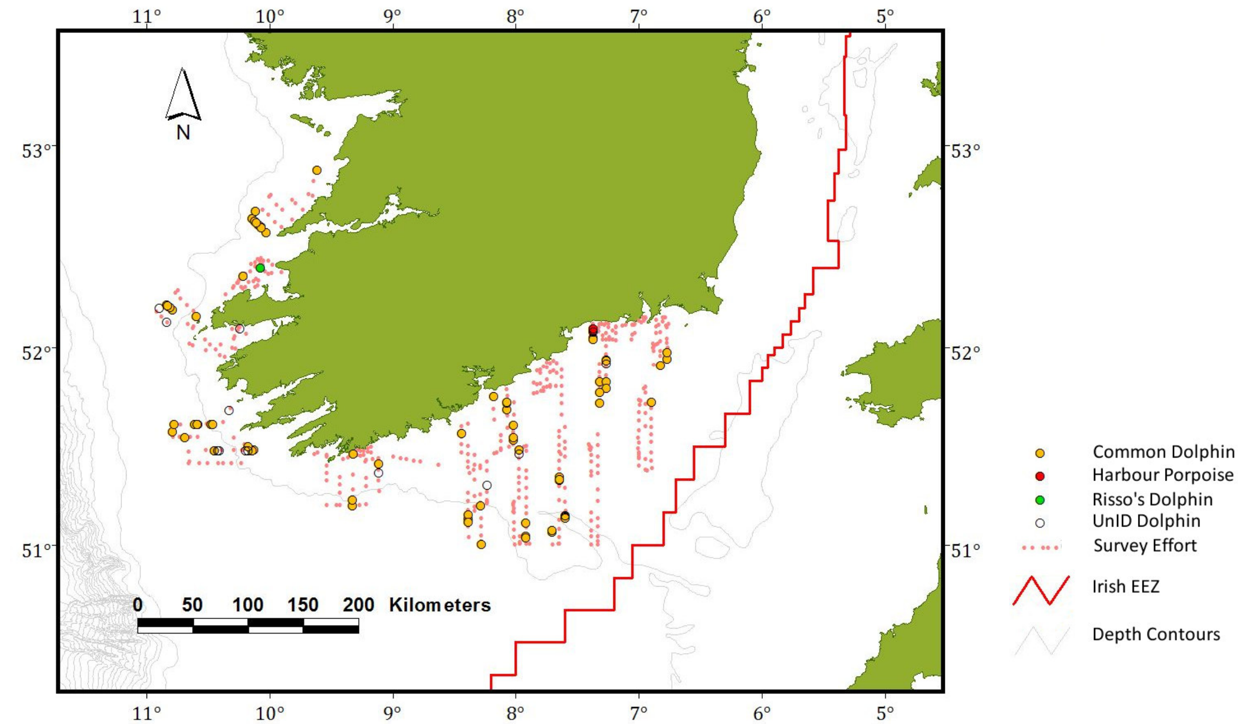


Figure 9. Distribution of dolphin sightings. Celtic Sea herring acoustic survey, October 2010.

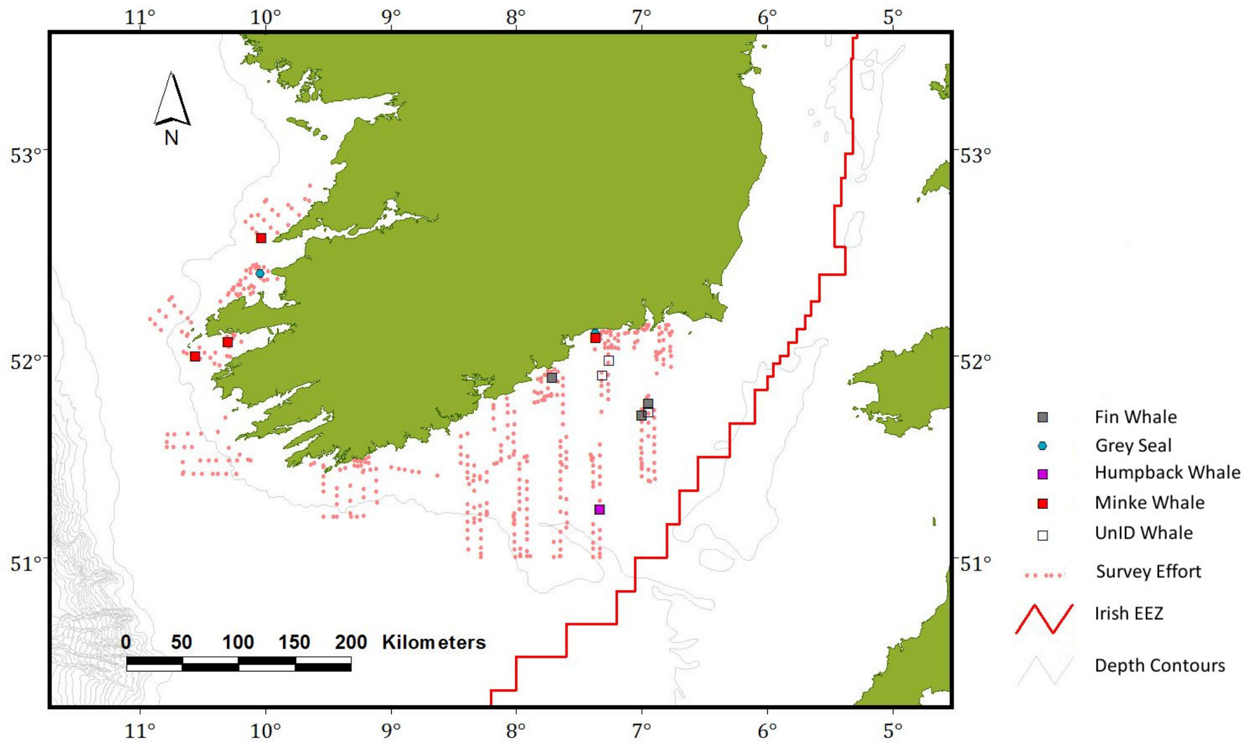


Figure 10. Distribution of whale and seal sightings. Celtic Sea herring acoustic survey, October 2010.

HERRING MIDWATER TRAWL

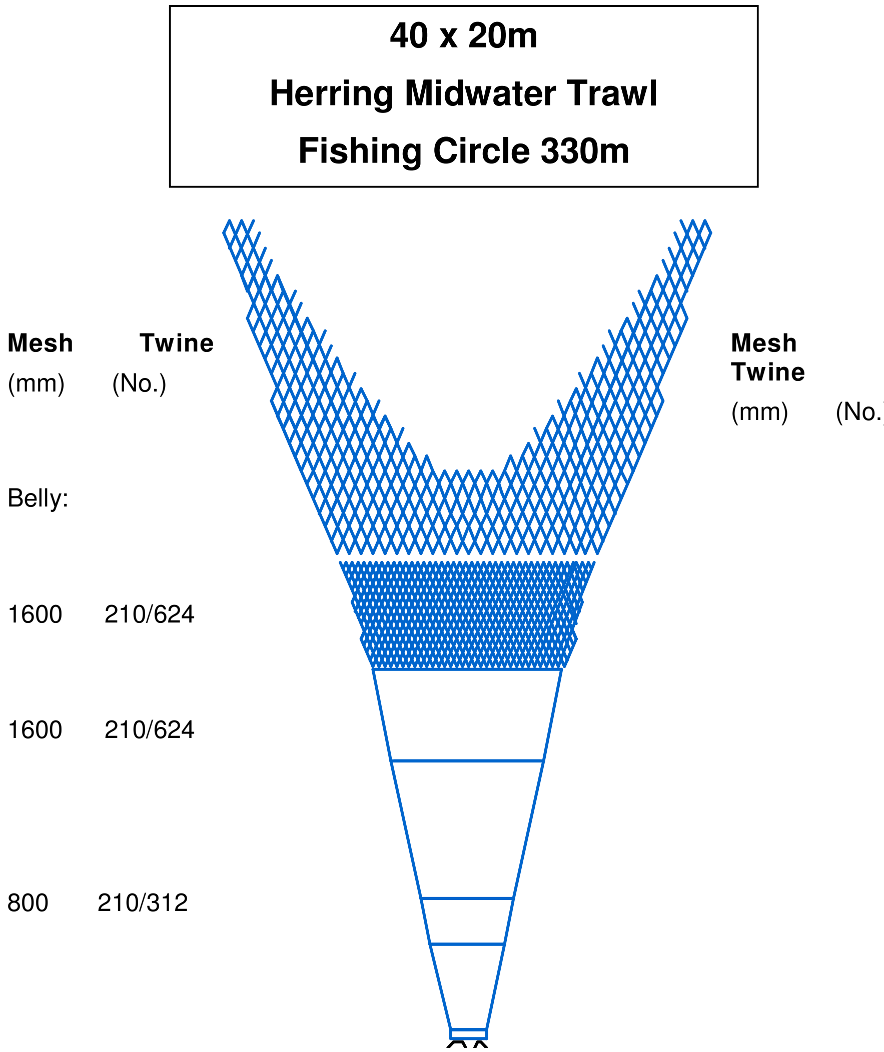


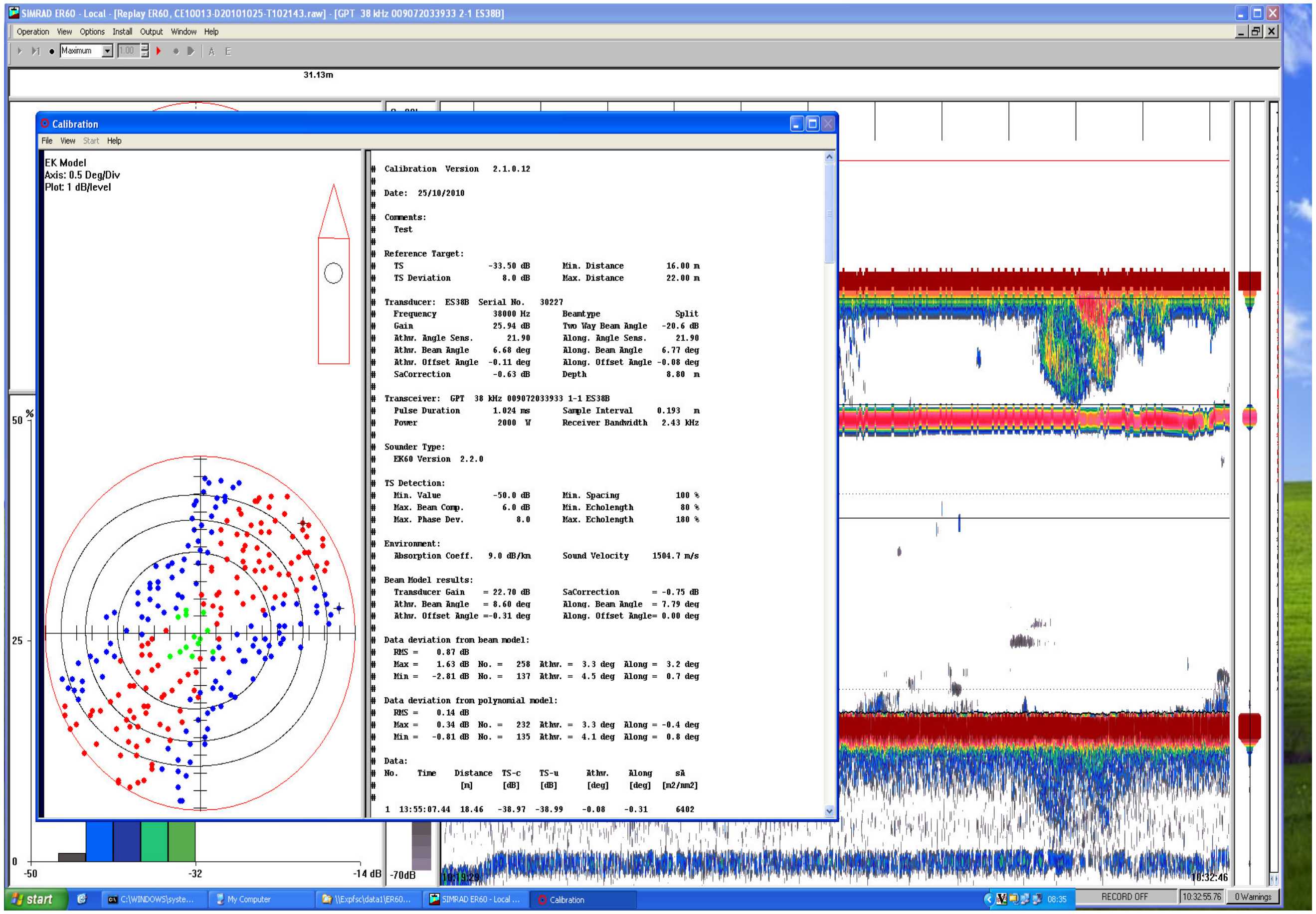
Figure 11. Single herring midwater trawl net plan and layout. Celtic Sea herring acoustic survey, October 2009.

Note: All mesh sizes given in half meshes, schematic does not show 32m brailer.

Annex 1: Calibration report

Annex Table 1. Calibration result of the Simrad ER60 ES38B (38 KHz) split beam transducer.

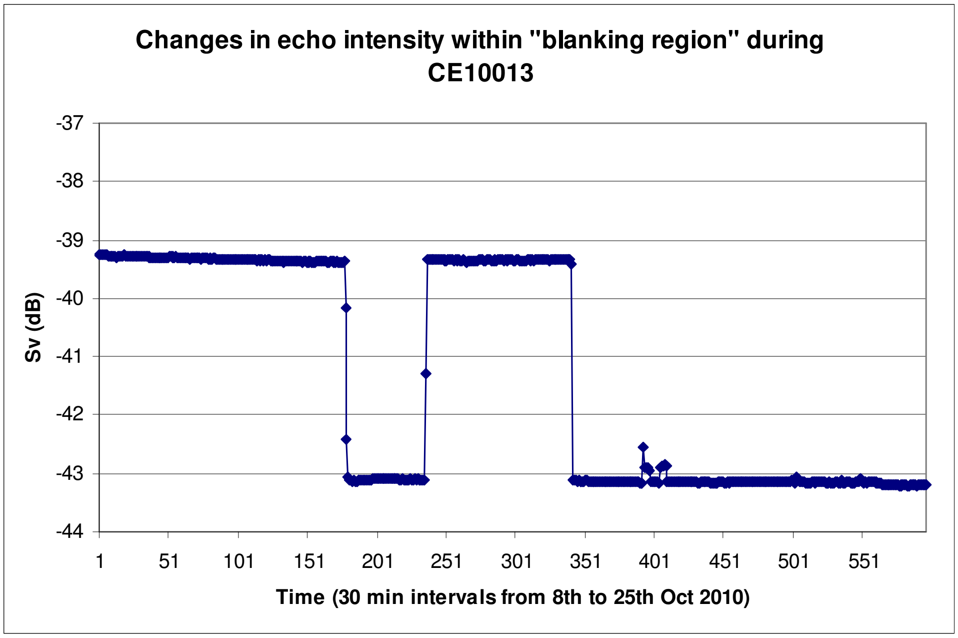
```
# Date: 25/10/2010
#
# Comments:
#   38 kHz Dunanus Bay CSHAS 2010
#
# Reference Target:
#   TS                  -33.50 dB     Min. Distance       13.20 m
#   TS Deviation                      8
#
# Transducer: ES38B Serial No. 30227
#   Frequency           38000 Hz      Beamtype            Split
#   Gain                25.94 dB      Two Way Beam Angle  -20.6 dB
#   Athw. Angle Sens.   21.90         Along. Angle Sens.  21.90
#   Athw. Beam Angle    6.68 deg      Along. Beam Angle   6.77 deg
#   Athw. Offset Angle  -0.11 deg     Along. Offset Angle -0.08 deg
#   SaCorrection        -0.63 dB      Depth               8.80 m
#
# Transceiver: GPT 38 kHz 009072033933 2-1 ES38B
#   Pulse Duration      1.024 ms      Sample Interval     0.193 m
#   Power               2000 W        Receiver Bandwidth  2.43 kHz
#
# Sounder Type:
#   EK60 Version 2.2.0
#
# TS Detection:
#   Min. Value          -50.0 dB      Min. Spacing        100 %
#   Max. Beam Comp.     6.0 dB        Min. Echolength     80 %
#   Max. Phase Dev.     8.0           Max. Echolength     180 %
#
# Environment:
#   Absorption Coeff.   9.0 dB/km     Sound Velocity      1504.7 m/s
#
# Beam Model results:
#   Transducer Gain     = 23.46 dB    SaCorrection        = -0.13 dB
#   Athw. Beam Angle    = 7.51 deg    Along. Beam Angle   = 8.49 deg
#   Athw. Offset Angle  =-0.17 deg    Along. Offset Angle=-0.21 deg
#
# Data deviation from beam model:
#   RMS =   0.57 dB
#   Max =   1.20 dB  No. =  63  Athw. =  3.4 deg  Along =  3.0 deg
#   Min =  -1.58 dB  No. =  95  Athw. =  0.4 deg  Along =  4.5 deg
#
# Data deviation from polynomial model:
#   RMS =   0.05 dB
#   Max =   0.12 dB  No. =   9  Athw. = -4.0 deg  Along = -1.7 deg
#   Min =  -0.15 dB  No. =  10  Athw. =  0.9 deg  Along =  4.0 deg
```



Annex Figure 1. Erroneous 38 kHz beam pattern observed during calibration in Dunmanus Bay.

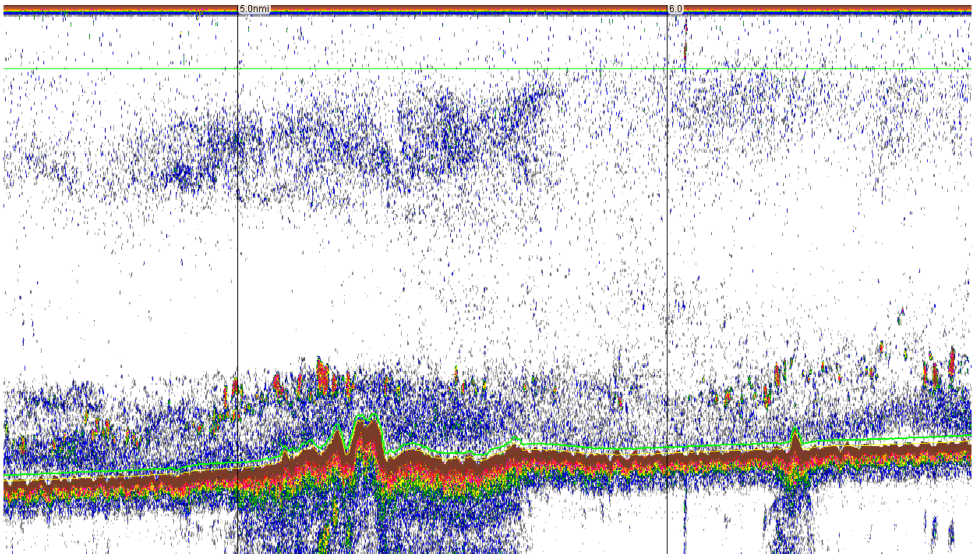
```
Calibration Version 2.1.0.12
#
# Date: 25/10/2010
#
# Comments:
#   18 kHz calibration Dunmanus Bay 25.10.10
#
# Reference Target:
#   TS                 -34.40 dB     Min. Distance       15.00 m
#   TS Deviation         5.0 dB      Max. Distance       25.00 m
#
# Transducer: ES18-11 Serial No. 2043
#   Frequency          18000 Hz      Beamtype              Split
#   Gain               23.07 dB      Two Way Beam Angle  -17.0 dB
#   Athw. Angle Sens.     13.90      Along. Angle Sens.    13.90
#   Athw. Beam Angle   10.53 deg     Along. Beam Angle  10.35 deg
#   Athw. Offset Angle -0.02 deg     Along. Offset Angle -0.01 deg
#   SaCorrection       -0.57 dB      Depth                8.80 m
#
# Transceiver: GPT 18 kHz 009072033966 1-1 ES18-11
#   Pulse Duration     2.048 ms      Sample Interval     0.385 m
#   Power              2000 W        Receiver Bandwidth  1.19 kHz
#
# Sounder Type:
#   EK60 Version 2.2.0
#
# TS Detection:
#   Min. Value         -50.0 dB      Min. Spacing          100 %
#   Max. Beam Comp.      6.0 dB      Min. Echolength        80 %
#   Max. Phase Dev.      8.0         Max. Echolength       180 %
#
# Environment:
#   Absorption Coeff. 2.4 dB/km      Sound Velocity   1504.7 m/s
#
# Beam Model results:
#   Transducer Gain    = 23.00 dB    SaCorrection      = -0.65 dB
#   Athw. Beam Angle   =10.37 deg    Along. Beam Angle =10.30 deg
#   Athw. Offset Angle =-0.06 deg    Along. Offset Angle= 0.01 deg
#
# Data deviation from beam model:
#   RMS =  0.19 dB
#   Max =  0.48 dB No. = 126 Athw. = 5.5 deg Along = -4.3 deg
#   Min = -0.71 dB No. = 301 Athw. = 3.0 deg Along =  4.1 deg
#
# Data deviation from polynomial model:
#   RMS =  0.17 dB
#   Max =  0.40 dB No. = 252 Athw. = 6.7 deg Along =  3.1 deg
#   Min = -0.74 dB No. = 301 Athw. = 3.0 deg Along =  4.1 deg
```

Annex Table 2. Calibration result of the Simrad ER60 ES38B (18 KHz) split beam transducer.

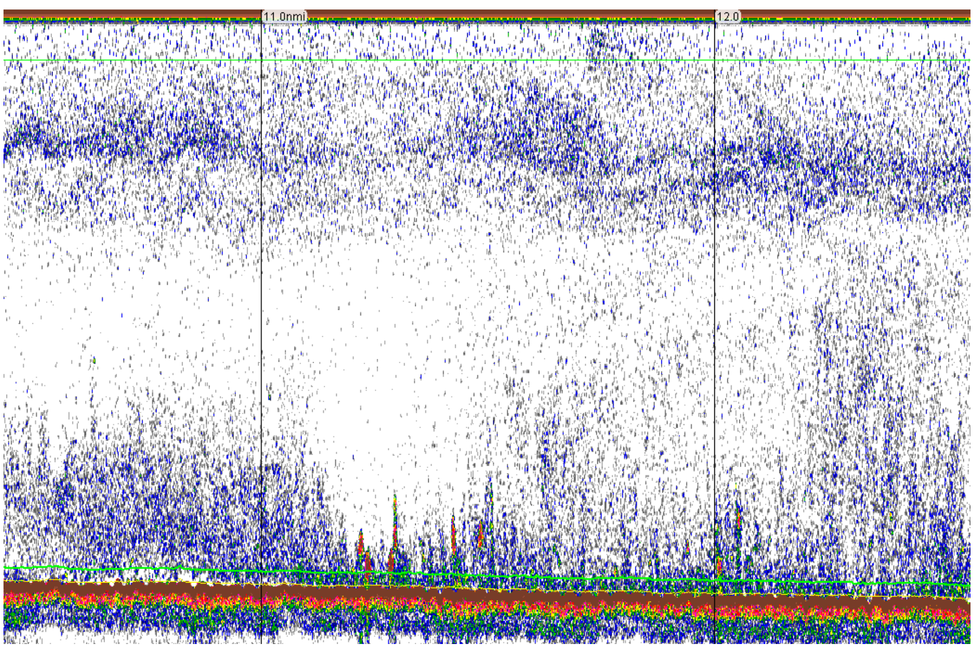


Annex Figure 2. Estimated output levels of the 38 kHz transducer throughout the 2010 survey. The distortion in beam pattern appeared to be an intermittent electrical problem. Note: this analysis only considers power output and the receiving capacity during the survey is not known.

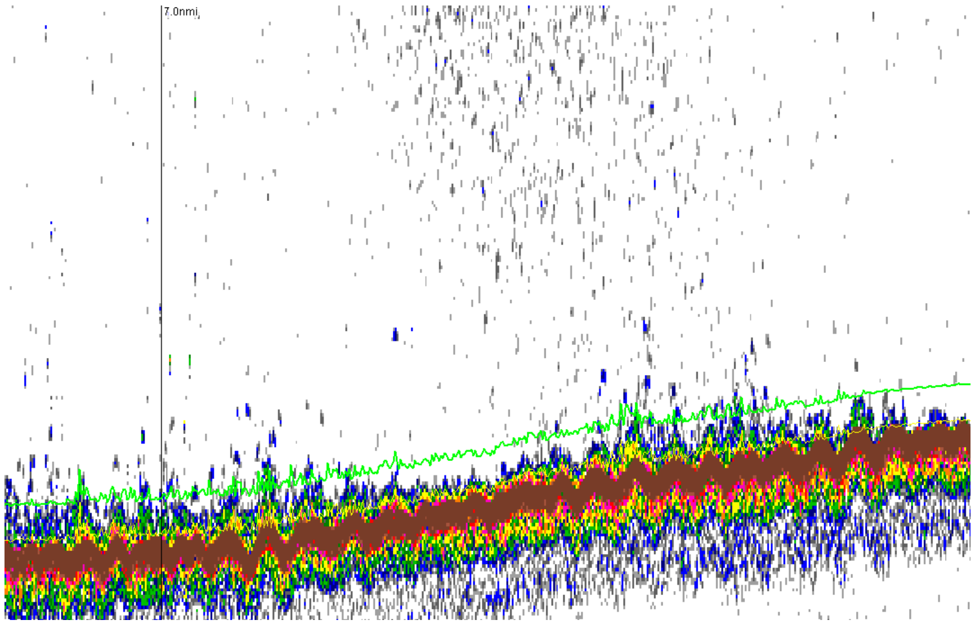
Annex 2: Echograms



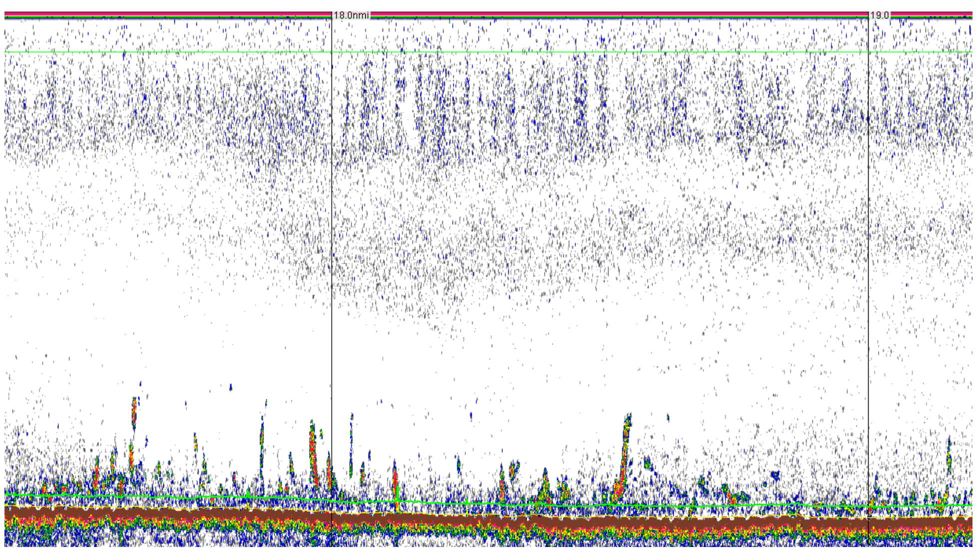
Haul 1 (09/10/10). Echotraces of sprat off Loop Head (Strata 1, transect 4)



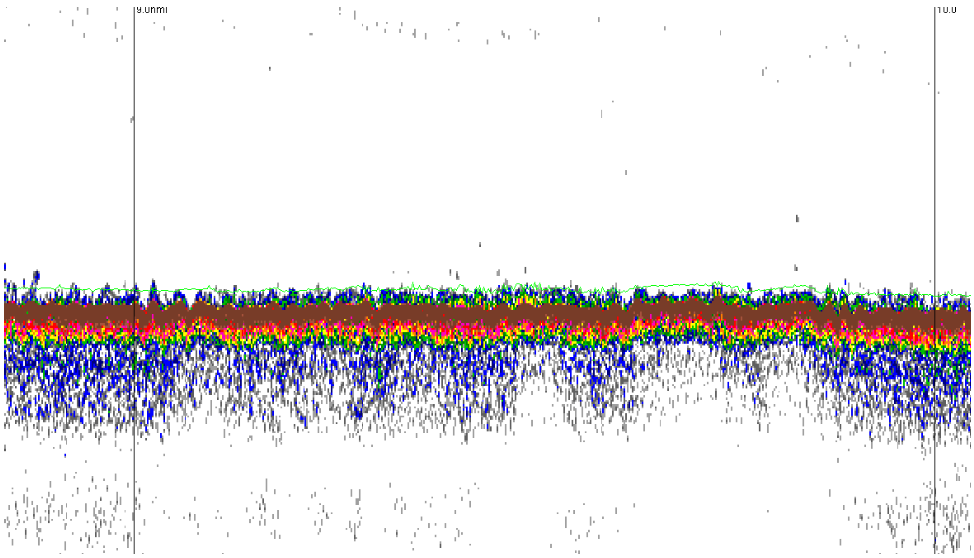
Haul 2 (13/10/10). Echotraces of herring offshore (Strata 9, transect 46)



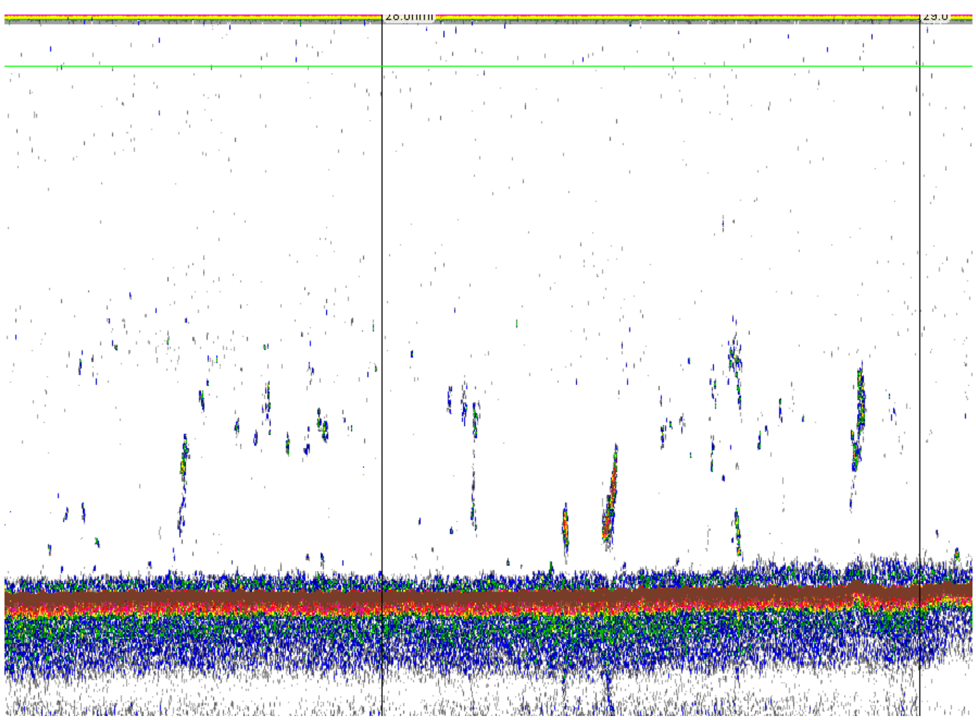
Haul 3 (14/10/10). Echotraces of herring pressed close to the seabed south of the Rigs (Strata 9, transect 49). Such targets were very difficult to detect acoustically.



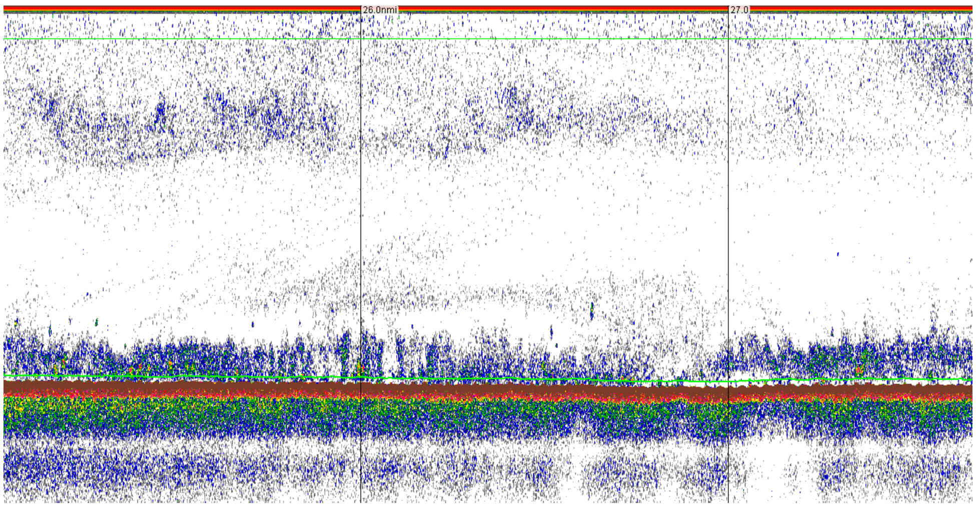
Haul 4 (14/10/10). Echotraces of herring south of the Rigs (Strata 9, transect 50)



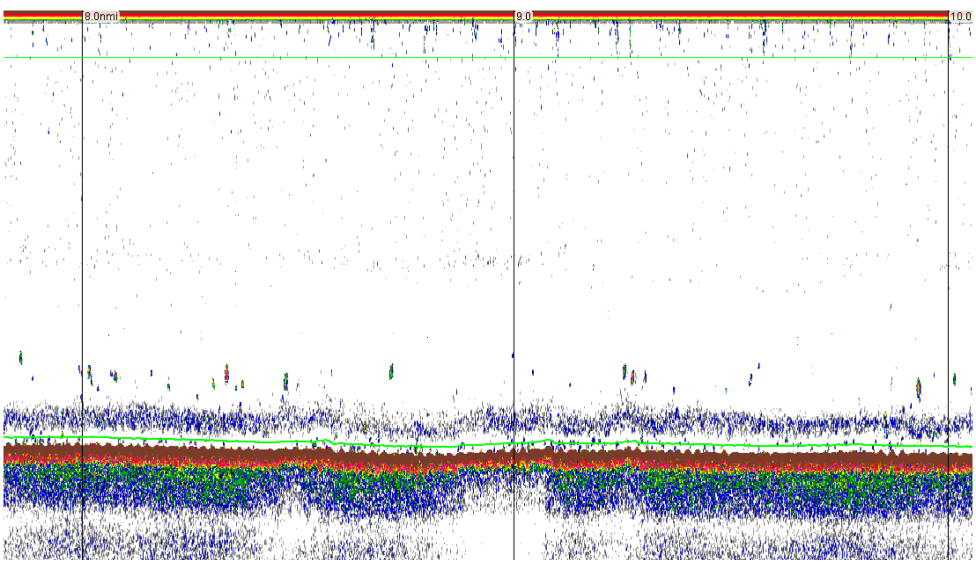
Haul 5 (15/10/10). Echotraces of herring pressed tight to the seabed (Strata 9, transect 56).



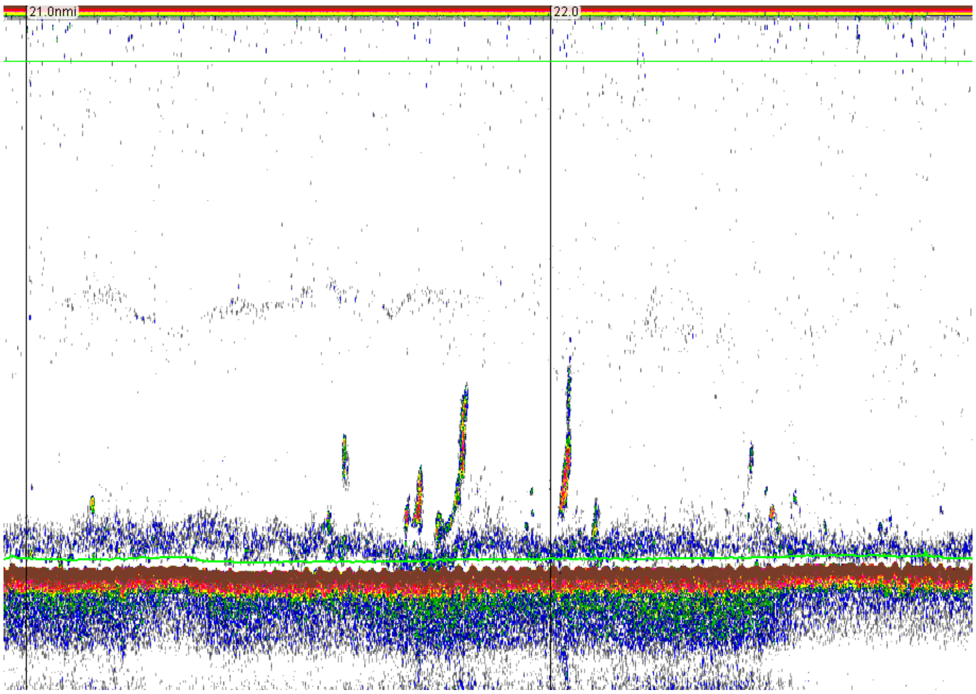
Haul 6 (15/10/10). Echotraces of herring distributed offshore (Strata 9, transect 57)



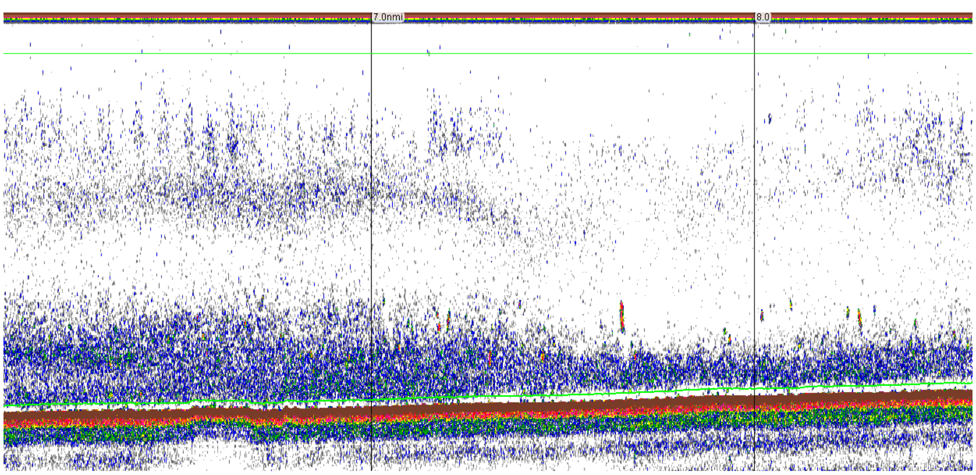
Haul 7 (15/10/10). Echotraces of sprat distributed close to the seabed (Strata 9, transect 58)



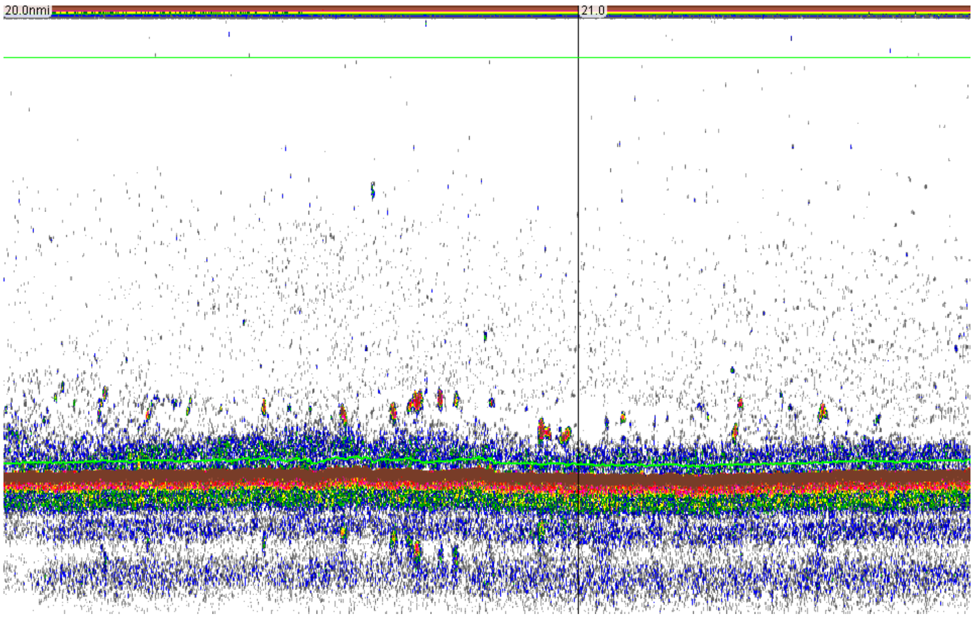
Haul 8 (16/10/10). Echotraces of sprat marked continuously for c. 8 nm (Strata 9, transect 62).



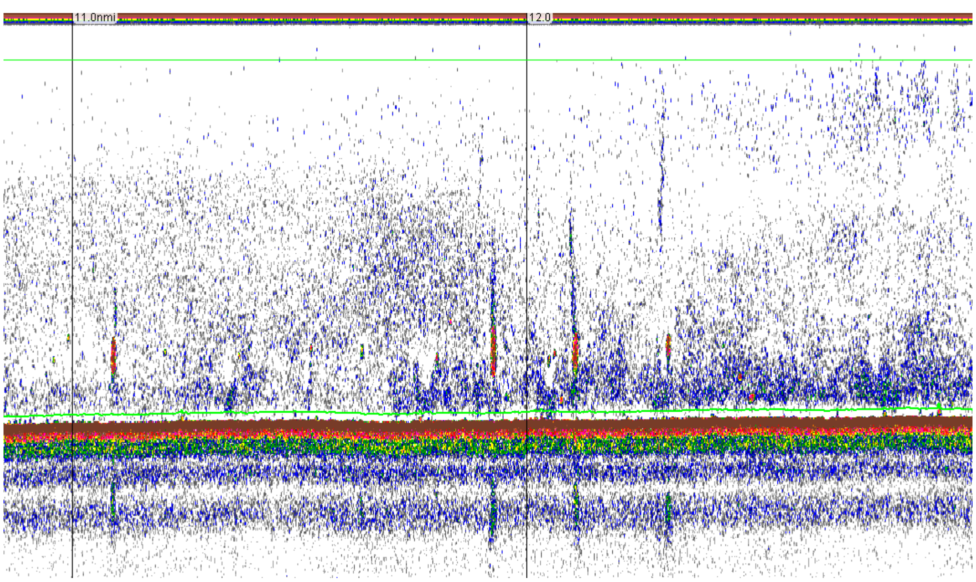
Haul 9 (16/10/10). Echotraces of mixed sprat and mackerel schools (Strata 9, transect 63).



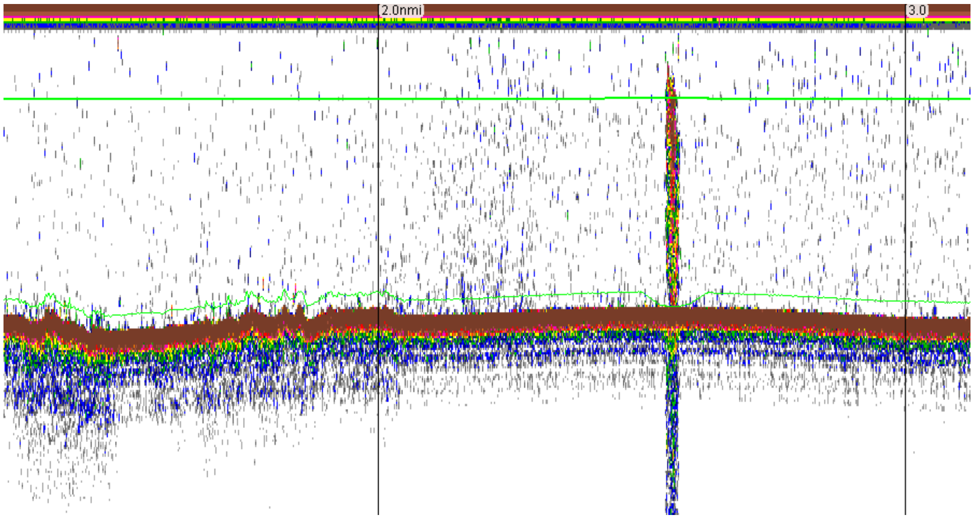
Haul 10 (17/10/10). Mixed sprat and mackerel schools marked continuously for c. 8 nm (Strata 9, transect 69)



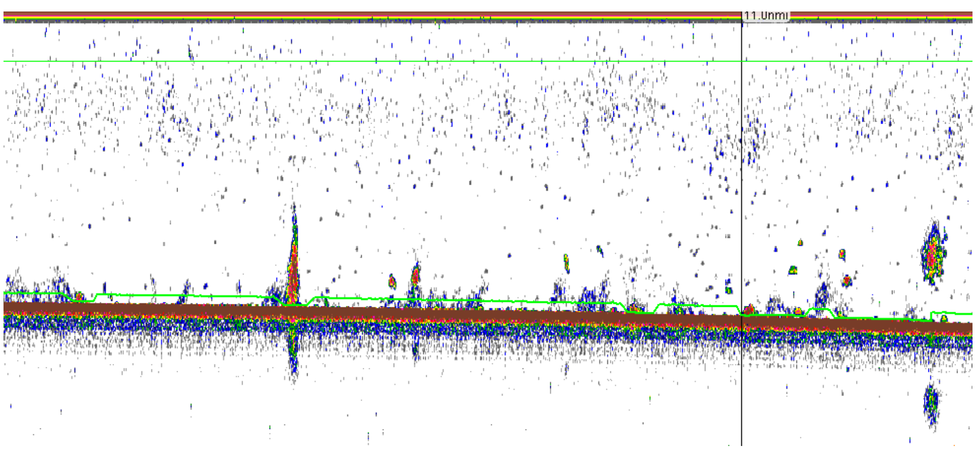
Haul 11 (17/10/10). Echotraces of sprat and mackerel (Strata 9, transect 71).



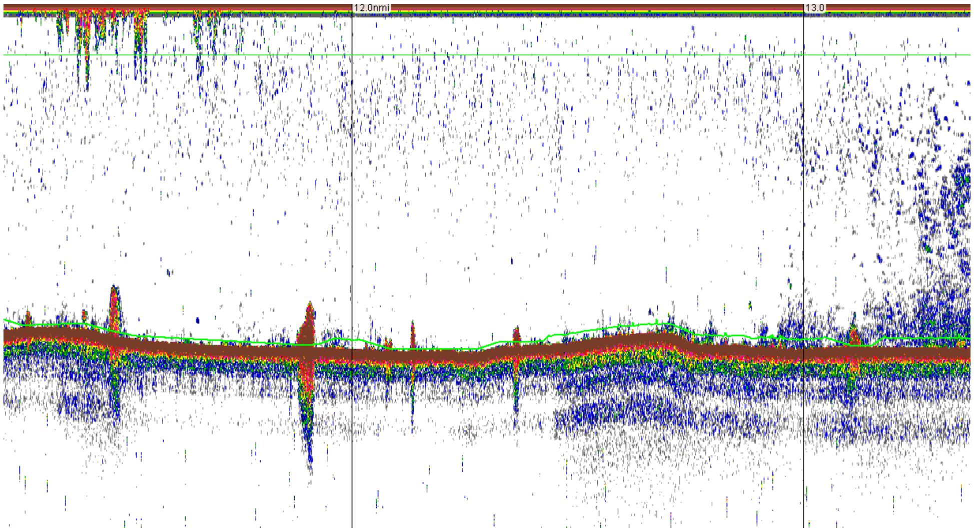
Haul 12 (17/10/10). Echotraces of sprat, mackerel and whiting (Strata 9, transect 72).



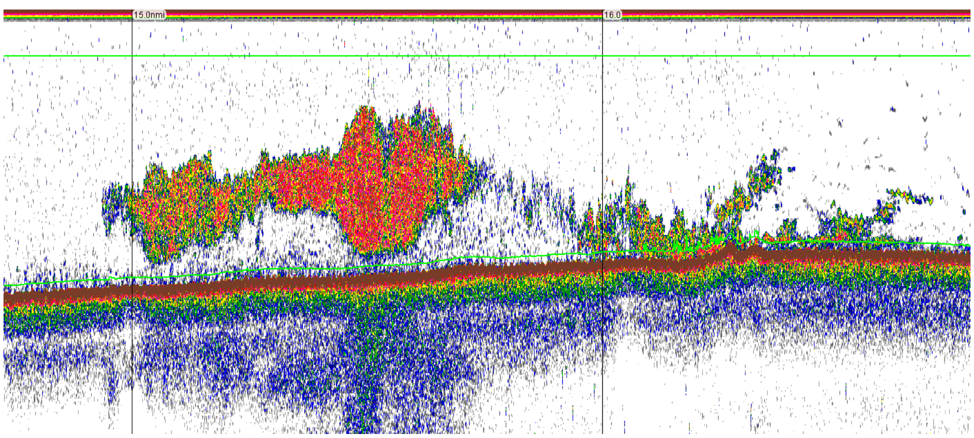
Haul 13 (18/10/10). Unknown echotrace due to net failure. Echotrace could possibly be herring (Strata 10, transect 74).



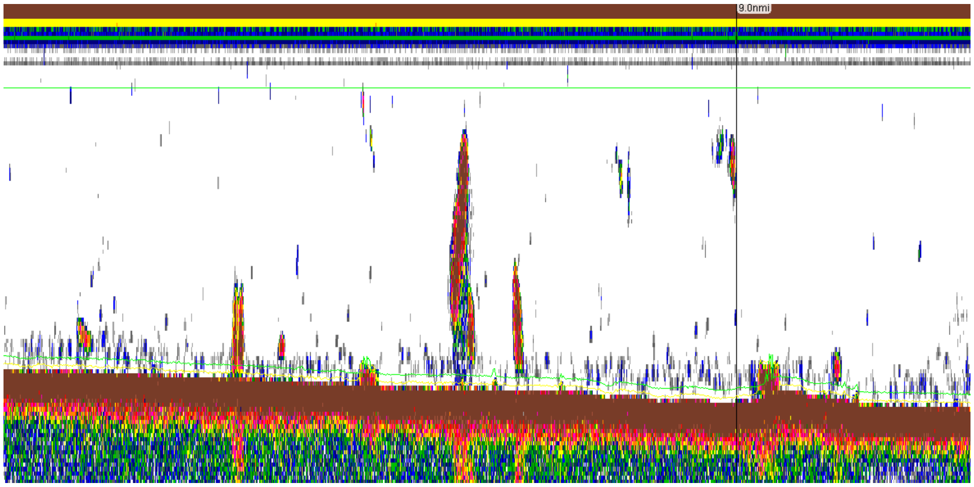
Haul 14 (18/10/10). Echotraces of herring off Baginbun (Strata 10, transect 76).



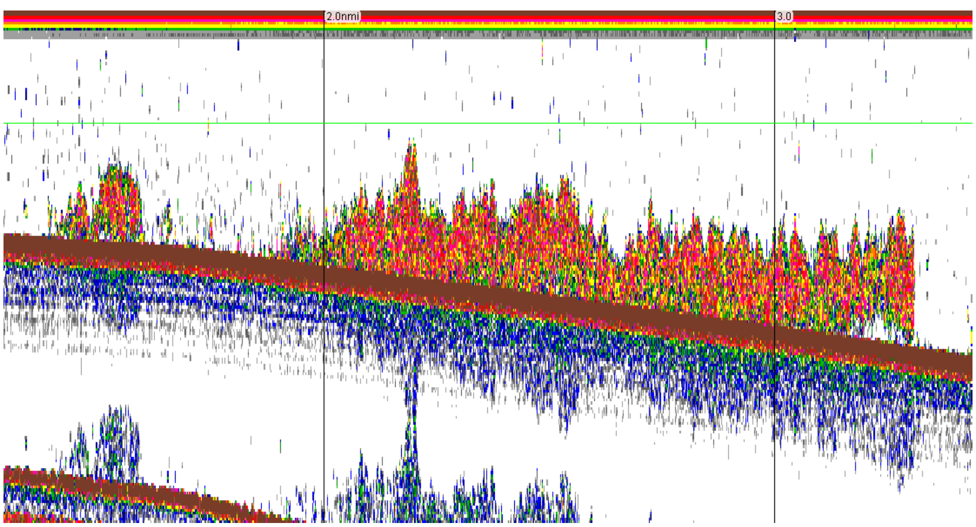
Haul 15 (16/10/10). Dense marks of herring off Baginbun (Strata 10, transect 78).



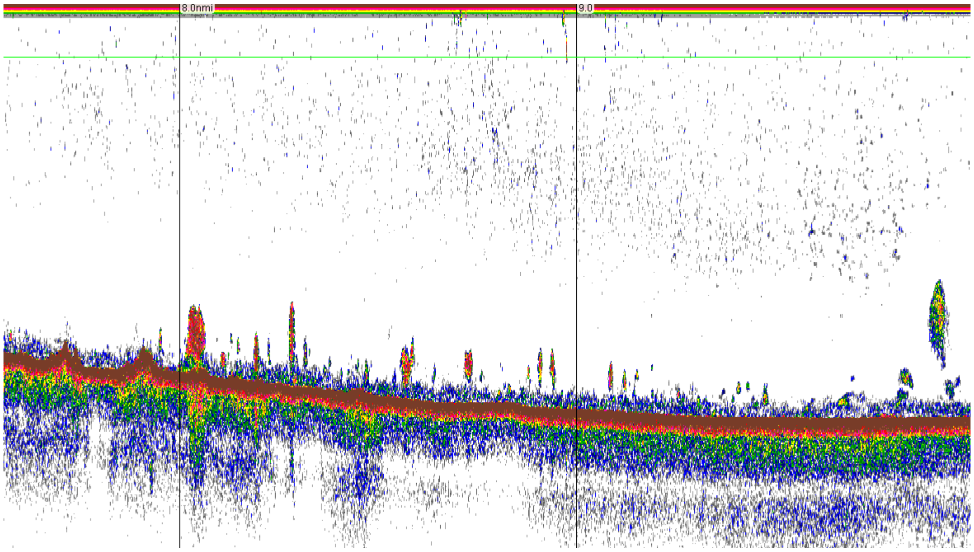
Haul 16 (16/10/10). Large school of herring off Brownstone Head (Strata 10, transect 60).



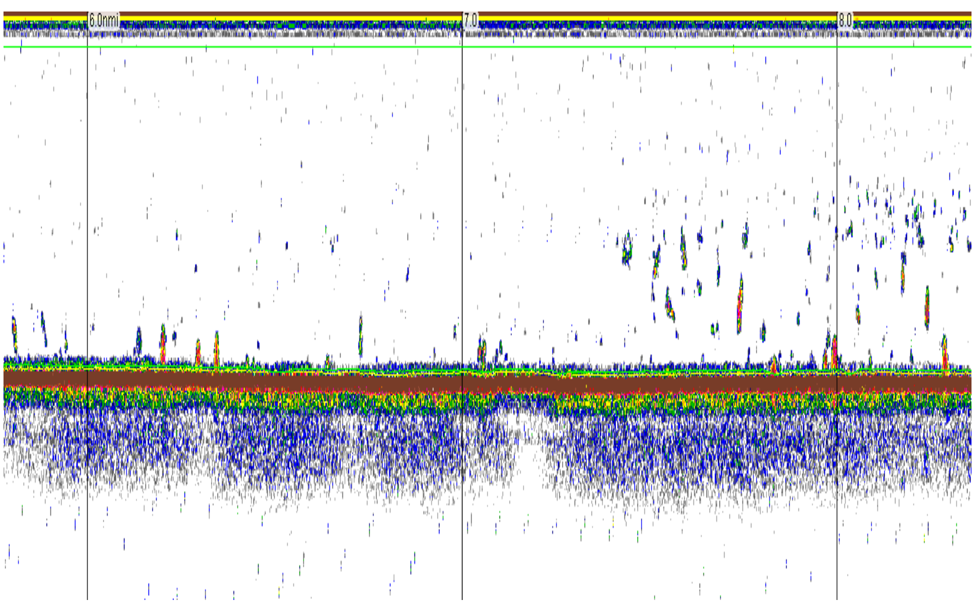
Haul 17 (19/10/10). Large schools of herring around Tramore Bay (Strata 12, transect 99).



Haul 18 (20/10/10). Large school of herring off Minehead (Strata 10, transect 115). Similar marks were often detected around Helvick Head and extended for 1-2 km



Haul 19 (21/10/10). Small schools of sprat around Ballycotton (Strata 14, transect 121).



Haul 20 (23/10/10). Small, scattered marks of herring around the mouth of Kinsale Harbour (Strata 15, transect 159).